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FISH PASSAGE ACTION PROGRAM FOR RED BLUFF DIVERSION DAM

FINAL REPORT ON FISHERY INVESTIGATIONS

U.S. FISH AND WILDLIFE SERVICE

REPORT NO. FR1/FAO-88-19

OCTOBER 1988

CHINOOK SALMON AND RED BLUFF DIVERSION DAM

C-045822

FISH PASSAGE ACTION PROGRAM
FOR
RED BLUFF DIVERSION DAM

FINAL REPORT

USFWS Report No. FR1/FAO-88-19

October 1988

Fisheries Assistance Office
U. S. Fish and Wildlife Service
P. O. Box 667
Red Bluff, California 96080

FINAL REPORT

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ABSTRACT

Red Bluff Diversion Dam (RBDD) was constructed on the upper Sacramento River and went into operation in 1966 to provide water into the Corning and Tehama-Colusa Canals. Investigations conducted during the 1970's and early 1980's showed that RBDD created significant adverse impacts on upstream and downstream migrating chinook salmon and steelhead trout. Based on these previous studies, a multi-agency five-year Fish Passage Action Program was initiated in October 1983 and completed in September 1988 to identify the specific problems with fish passage at the dam and develop actions and recommendations to resolve those problems.

A variety of specific conclusions and recommendations were developed regarding predation, entrainment, and physical injury losses, and problems associated with delay in juvenile salmon and steelhead passage. The studies demonstrated that fry-sized and smolt-sized salmon migrate past the dam every month of the year. It was determined that predation (primarily by squawfish) is the major cause of downstream migrant salmon mortality at the dam. The losses due to predation can be severe; recommendations are given to develop and evaluate measures to reduce those losses.

Delay and blockage of adult salmon at the dam were identified as severe. Attempts to operate the dam gates to improve fish attraction into the fish ladders were unsuccessful. We found that there are major problems in operating the fish ladders at maximum design flow capacity and that the ladders do not provide sufficient fish attraction even when they are operated at maximum flow capacity.

Recommendations to improve adult salmonid passage at the dam are presented. These recommendations included: constructing a new large-scale fish

ladder on the left (northeast) bank, enlarging the size and flow capacity of the existing ladders, raising the dam gates during the non-irrigation season, and establishing a permanent program to ensure proper operation and maintenance of all fish passage facilities.

INTRODUCTION

Construction of Red Bluff Diversion Dam (RBDD) was completed on the upper Sacramento River in the northern portion of California's Central Valley in 1964. It is located 243 river miles above San Francisco Bay near the town of Red Bluff (Figure 1). The purpose of the dam is to divert water into the Tehama-Colusa (T-C) and Corning Canals (Figure 2). Water conveyed through the T-C Canal is used for agriculture, wildlife refuges, and the Tehama-Colusa Fish Facilities. The Corning Canal is used only for agriculture. RBDD began operation when the dam gates were lowered in August 1966.

The Sacramento River is the migratory route for chinook salmon and steelhead trout which spawn upstream from RBDD. The four runs of chinook salmon in the Sacramento River (fall, late-fall, winter, and spring runs) are important to the commercial and sport fisheries of California. Steelhead are important to the sport fishery (there is no commercial fishery for steelhead).

The declining populations of salmon and steelhead in the upper Sacramento River during the 1970's and early 1980's prompted investigations by concerned agencies and public groups. Conclusions reached in many of these studies attributed much of the fishery declines to RBDD. Substantial evidence surfaced which showed that RBDD impedes the upstream migration of anadromous salmonids to their natural spawning habitat and adversely affects the downstream passage of juvenile salmonids enroute to the ocean.

Based on annual aerial counts of fall-run salmon redds (nests) conducted by the California Department of Fish and Game (CDFG), the proportion of fall-spawning chinook salmon in the upper Sacramento River utilizing the river above Red Bluff declined substantially since RBDD was put into operation (Figure 3). In addition, Hallock, et al. (1982) concluded that RBDD is a

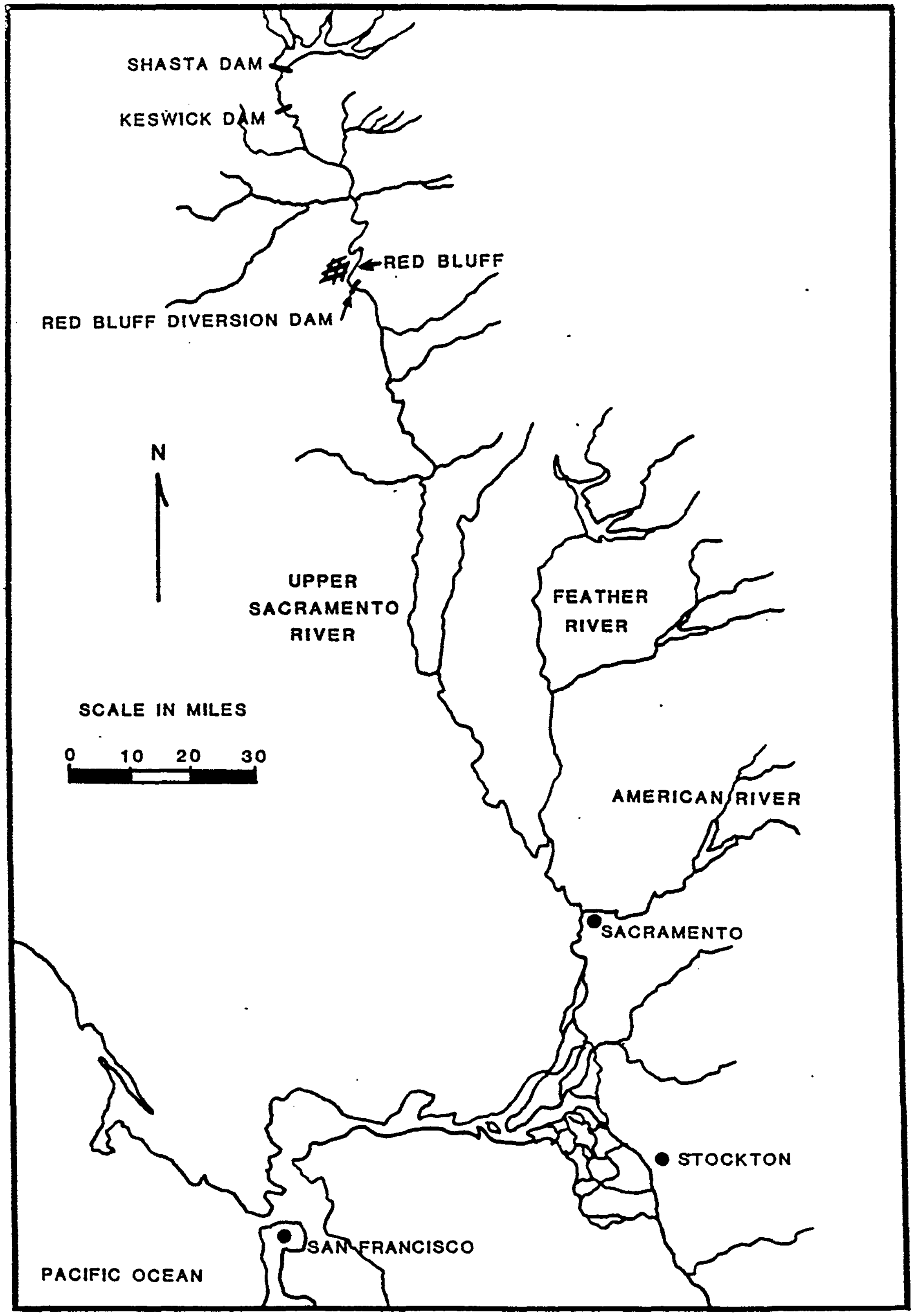


Figure 1. Location of Red Bluff Diversion Dam on the Upper Sacramento River in northern California.

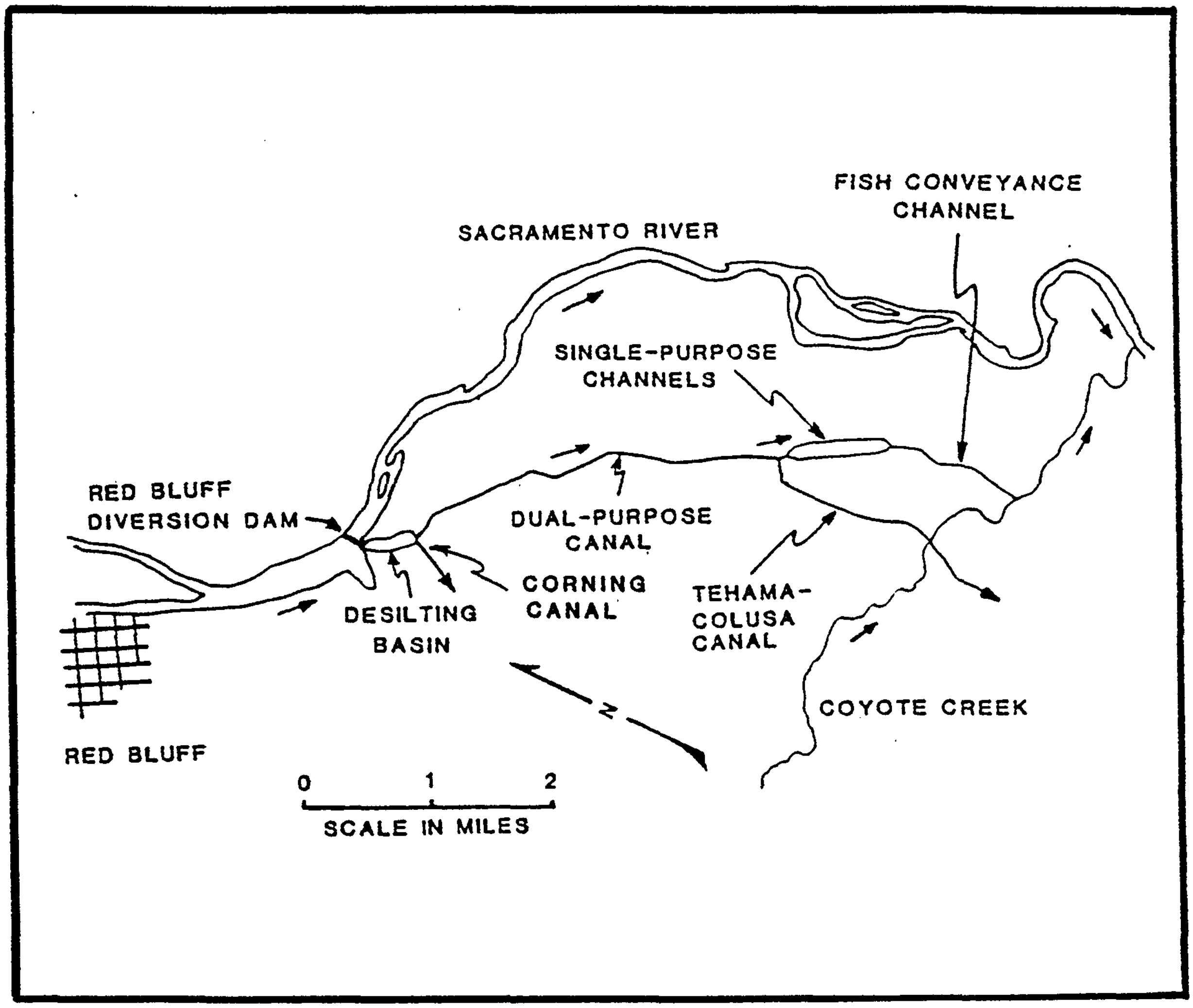


Figure 2. Location of the Tehama-Colusa and Corning Canals.

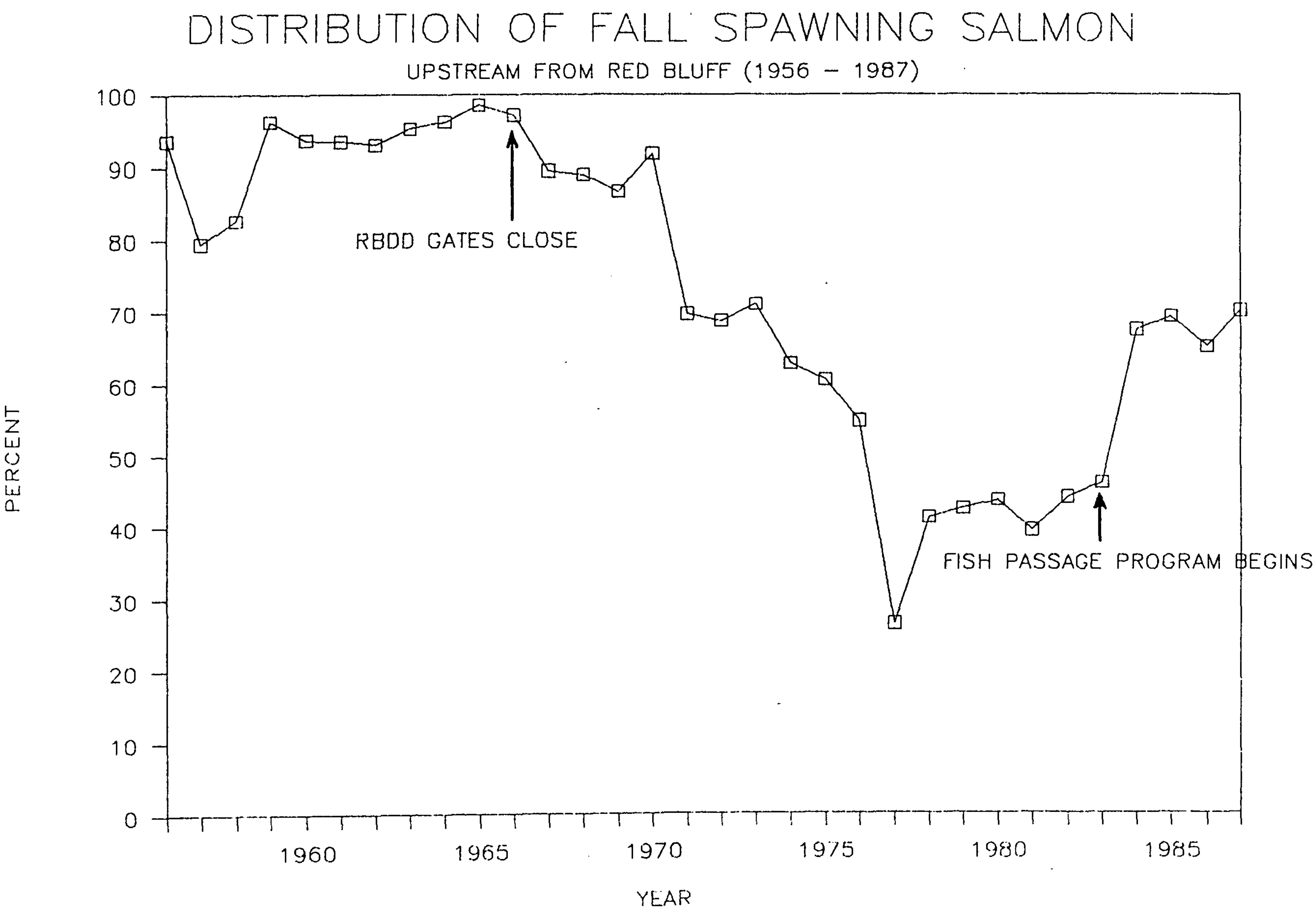


FIGURE 3. PROPORTION OF FALL-SPAWNING CHINOOK SALMON IN THE UPPER SACRAMENTO RIVER UTILIZING THE RIVER ABOVE RED BLUFF.

major impediment to all four races of adult salmon attempting to migrate upstream past the dam.

Another significant fishery problem identified at RBDD is downstream migrant salmonid mortality. CDFG conducted studies which indicated that substantial mortality can occur for juvenile salmonids passing RBDD (Hall 1977; Hallock 1980; Hallock 1983). However, other than predation mortality studies conducted by Hall (1977) and Vondracek and Moyle (1983), none of the downstream migrant studies provided an indication of the specific causes of the high juvenile salmonid mortality.

Although all the past fishery studies at RBDD developed valuable data, none of the evaluations were predicated on identifying specific solutions to the upstream and downstream fish passage problems created by RBDD.

Based on results of the previous studies conducted at RBDD and recognizing the need for action, the U.S. Bureau of Reclamation (USBR), the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Game, the National Marine Fisheries Service, and the California Department of Water Resources initiated this five-year Fish Passage Action Program in October 1983 to develop methods to improve upstream and downstream anadromous fish passage at RBDD. The purpose of this program was to identify specific problems and develop and implement corrective measures.

This final report summarizes the results of the U.S. Fish and Wildlife Service in their field and program analysis tasks in the five-year program. The USBR will prepare a Regional Office report during 1988-1989 which will identify the benefits and costs of the recommendations of this report.

DOWNSTREAM MIGRANT SALMONID PASSAGE

The downstream migrant salmonid passage evaluation portion of the Fish Passage Program was designed to pinpoint specific causes of fry and juvenile fish passage problems at RBDD. There are four possible causes of downstream migrant salmonid mortality at RBDD:

1) Losses attributable to diversion into the T-C and Corning Canals.
2) Direct injury from passing under the dam gates or through the fish louver bypass facility.
3) Delay of juvenile salmonids in Lake Red Bluff which could cause downstream migrants to be asynchronous with normal smoltification and with seasonal cycles of water temperatures and food production in the lower river or ocean, and
4) Predation resulting from ideal conditions created by RBDD for piscivorous fishes and birds in Lake Red Bluff or immediately below the dam.

Abundance and Sizes

An important element in the evaluation of the interaction of downstream migrant salmonids and Red Bluff Diversion Dam is an understanding of Sacramento River fry and juvenile salmonid movements. From the onset of the Fish Passage Program, all five agencies associated with the program realized that an index of salmonids approaching the dam on a daily basis would be useful in analyzing impacts caused by the dam and necessary in the development of measures to eliminate or alleviate those impacts. Such a data base would also provide benefits for activities outside the scope of the Fish Passage Program where an understanding of Sacramento River fry and juvenile salmonid abundance and movements would be useful.

A program conducted concurrently with the RBDD Fish Passage Program was the T-C Canal Diversion and Fishery Problems Study. Within this latter program, a daily data base was developed which displayed the total numbers and sizes of young salmon entrained through the T-C Canal headworks (Figure 4) which was invaluable in the development of indices for downstream migrant salmonids approaching RBDD.

Additional information beyond the scope of the T-C entrainment evaluation had to be developed prior to the development of downstream migrant indices at RBDD. The reason for this is that there was a lack of detailed understanding of the proportion of downstream migrants diverted off the Sacramento River into the T-C Canal headworks and the screening efficiency of the fish louvers within the headworks (Figure 4). For this reason, data on these latter two elements were developed during the course of the Fish Passage Program to be used in conjunction with the daily entrainment data for the T-C Canal study in order to derive the downstream migrant indices. The methods on how each of these data bases were developed (i.e. entrainment, fish louver screening efficiency, and proportion of salmon diverted) are described in detail in Appendix I.

Results of the fish louver screening efficiency evaluation are displayed in Figure 5 and Appendix II Table 1. For young salmon of a size greater than 50-60 millimeters (mm) in fork length, screening efficiency averaged 98 percent. However, for smaller-sized fish, screening efficiency dropped off markedly and was less than 40 percent for the smallest-sized salmon fry exposed to the louvers.

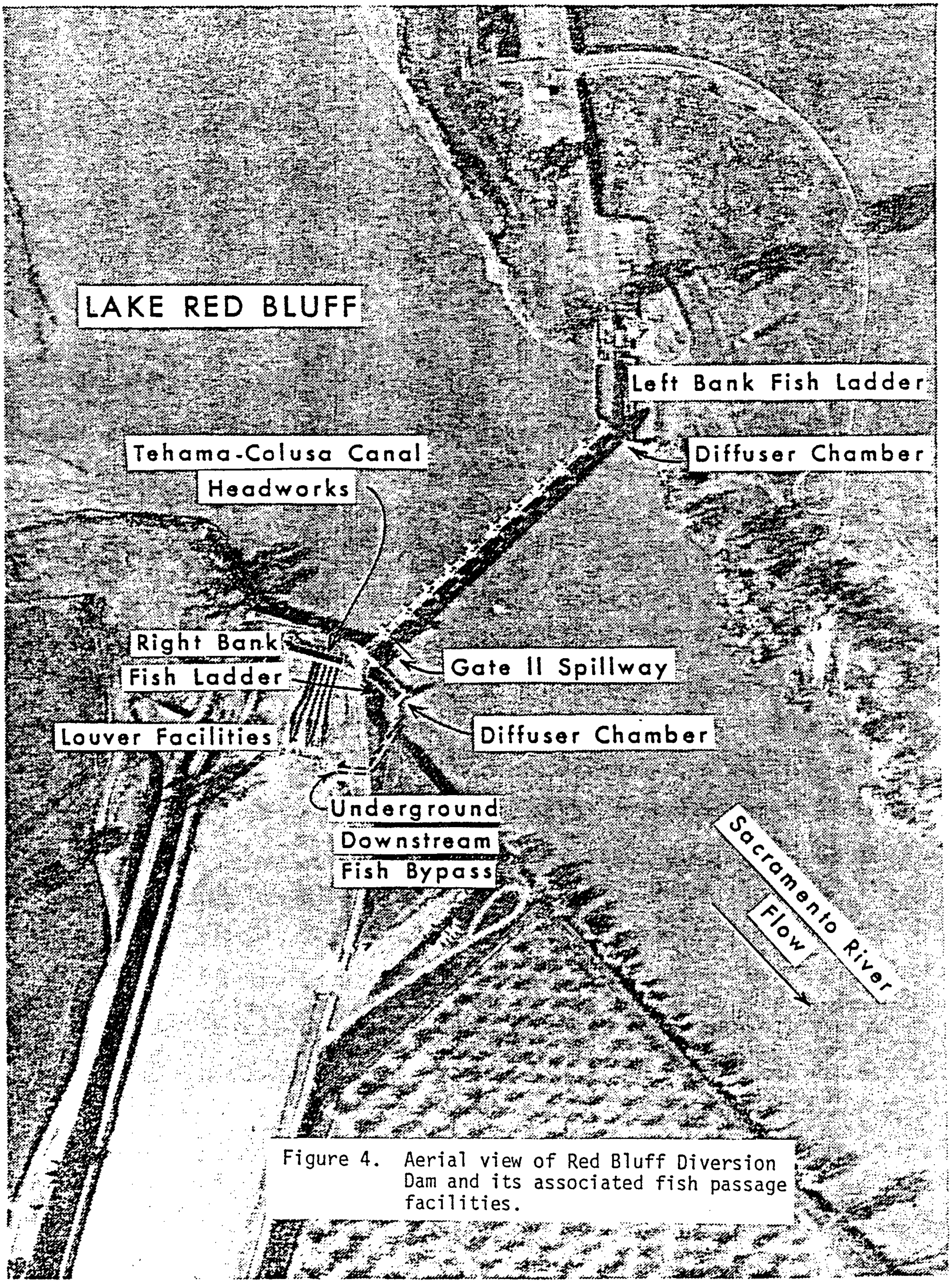


Figure 4. Aerial view of Red Bluff Diversion Dam and its associated fish passage facilities.

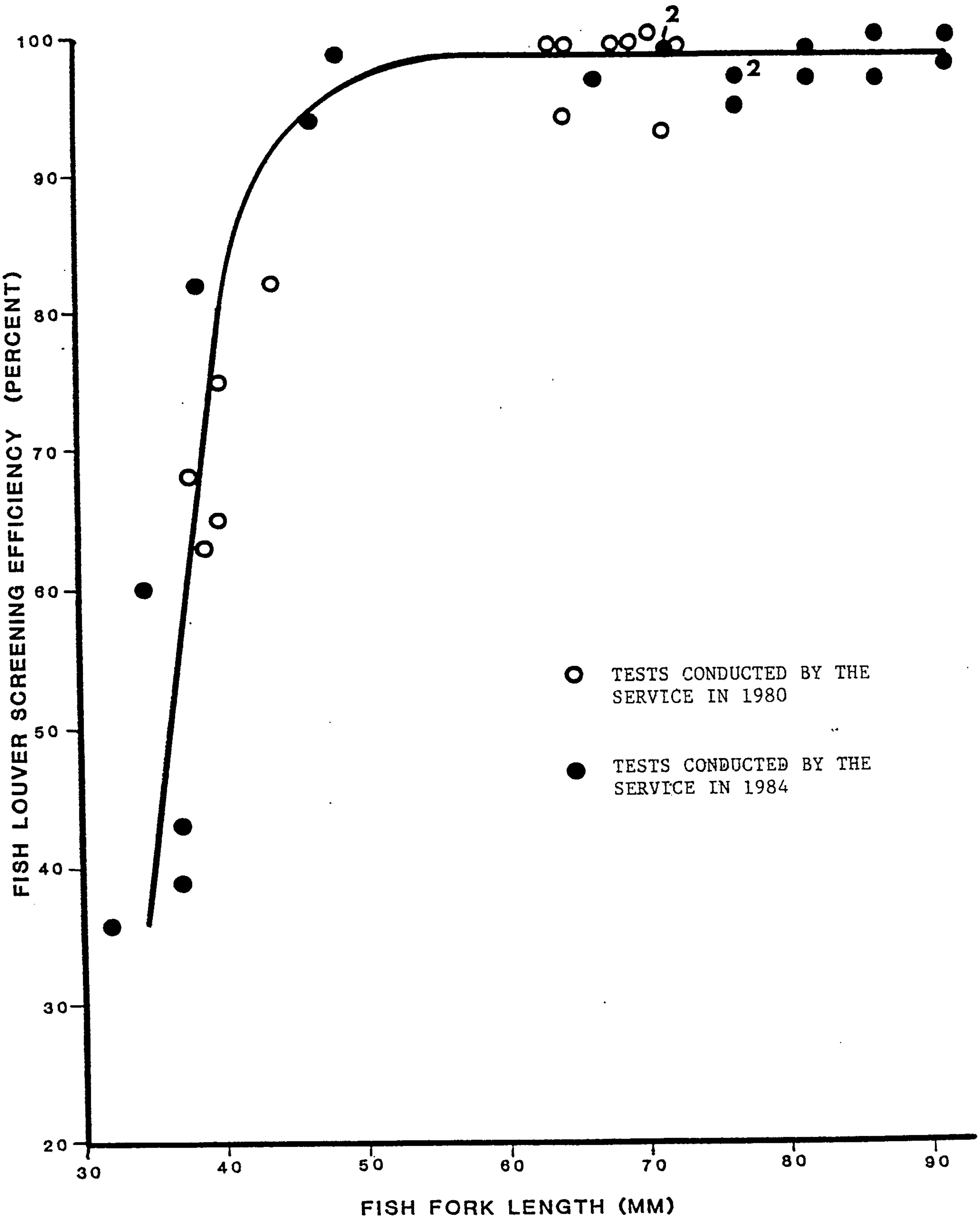


Figure 5. Louver screening efficiency for young chinook salmon released into the T-C Canal Headworks.

Knowing the numbers and sizes of young salmon entrained through the fish louvers (data derived from the T-C Canal Study), the louver screening efficiency data were used to provide an indication of the numbers of young salmon approaching the louvers by a simple backcalculation using each day's entrainment of young salmon into the T-C and Corning Canals and their mean size:

$$T_N = \frac{C_N}{(1 - LE)}$$

where: T_N = Total number of downstream migrant salmon approaching the fish louvers on day N.

C_N = Total entrainment of downstream migrant salmon in the T-C and and Corning Canals on day N.

LE = Louver screening efficiency (proportion) for the mean fish size (fork length) of C_N.

The use of mean fish size biases the estimate somewhat because of the non-linear relationship of screening efficiency among all fish sizes. However, because most of the fish encountering the louvers were generally of a contracted size distribution within a linear screening efficiency range, we believe the estimate derived from this calculation is reasonably reflective of actual fish numbers. See Appendix I Methods for a more detailed explanation.

The next phase in the backcalculation process to derive the downstream migrant indices was to estimate the proportion of downstream migrants approaching RBDD that are diverted into the T-C headworks (upstream of the louvers) on a daily basis. To do this, we conducted an evaluation of the lateral distribution of downstream migrants approaching RBDD (methods described in Appendix I); the results are given in Table 1.

These results indicated that the downstream migrants (of all combined size ranges) approaching the dam at night were not uniformly distributed across the river channel ($F_{2,48}$ = 5.20, $P < 0.01$). However, for the larger-sized downstream migrants (> 60 mm) there was no significant difference ($F_{2,15}$= 0.68, $P > 0.10$) in their distribution which indicated that they were distributed uniformly across the river channel. The greatest disparity in distribution for fish all size ranges was between the mid-channel and the left

Table 1. Lateral distribution of fry and juvenile chinook salmon approaching Red Bluff Diversion Dam (facing downstream).

Sampling Period	Number of Samples		Right Bank	Mid-Channel	Left Bank
2/18/88- 2/29/88	11	Mean	31.4%	39.5%	29.1%
		Range	21.4%-48.6%	32.6%-46.5%	16.5%-38.4%
		Mean Fish Fork Length	37 mm	37 mm	37 mm
4/20/88- 5/19/88	6	Mean	35.4%	35.3%	29.3%
		Range	17.5%-49.5%	24.6%-47.4%	16.3%-40.3%
		Mean Fish Fork Length	68 mm	67 mm	60 mm
2/18/88- 5/19/88	Combined 17	Mean	32.8%	38.0%	29.2
		Range	17.5%-49.5%	24.6%-47.4%	16.3%-40.3

third of the channel. In most cases, the right third of the river channel accommodated approximately one-third (32.8%) of the downstream migrants. For this reason and because of the configuration of the headworks intake 1/, we believe it is reasonable to conclude that downstream migrant salmon are diverted into the T-C headworks in direct proportion to the amount of flow diverted. Using this assumption, the following formula was derived to develop the daily downstream migrant indices:

1/ The T-C headworks intake, located on the right bank, is on a near-vertical wall and withdraws water from the surface to a depth of 9.5 feet below the surface during the irrigation season.

$$I_N = \frac{T_N}{D_N}$$

Where: I_N = Downstream migrant index (number of salmon approaching RBDD on day N.

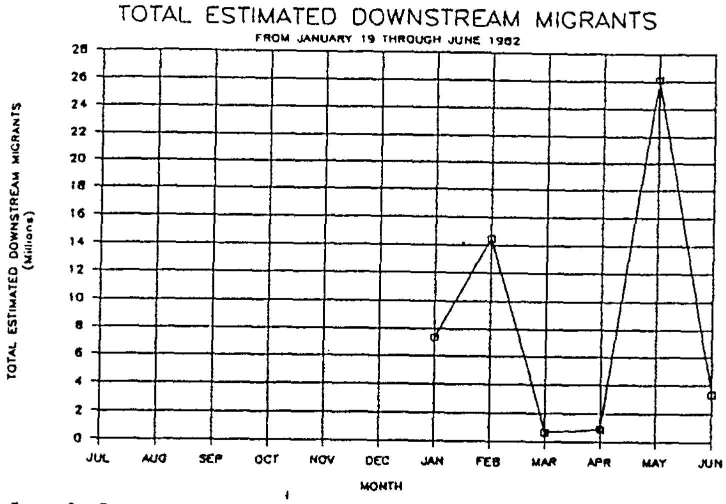
T_N = Total number of downstream migrant salmon approaching the fish louvers on day N.

D_N = Diversion rate or the proportion of the total Sacramento River flow diverted into the T-C headworks on day N.

The daily downstream migrant index (I_N) could then be extrapolated to develop annual indices of the total number of downstream migrant salmon approaching RBDD each year of the study. These totals are given in Table 2 and are displayed by month in Figures 6 - 12 .

Table 2. Downstream migrant indices of young salmon (millions) approaching RBDD (January 19, 1982 - November 30, 1987).

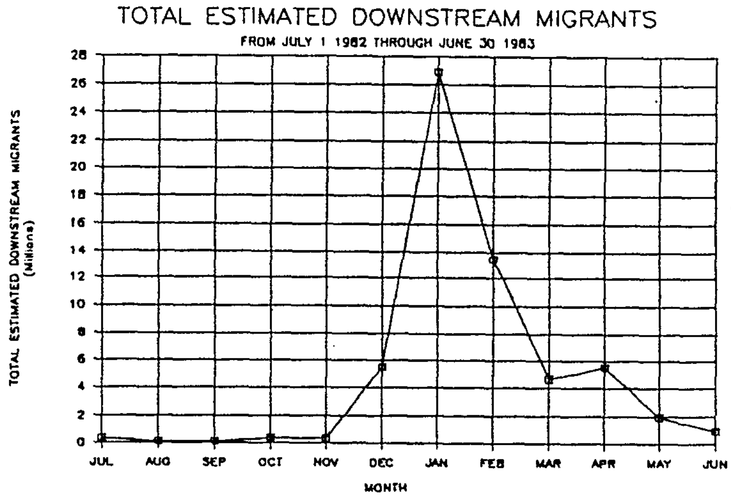
Time Period	Downstream Migrant Index (Millions of Salmon)	ESCAPEADS	
January 19, 1982 - June 30, 1982	53	115509	54
July 1, 1982 - June 30, 1983	60	211695	55
July 1, 1983 - June 30, 1984	22	212739	56
July 1, 1984 - June 30, 1985	49	150965	57
July 1, 1985 - June 30, 1986	155	197541	58
July 1, 1986 - June 30, 1987	35	116726	
July 1, 1987 - November 30, 1987	1		



DEC
WET FEB, APRIL

RET 115509

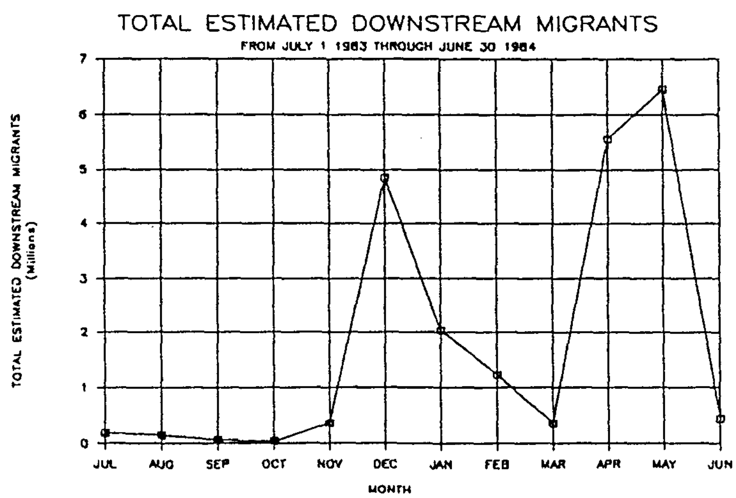
FIGURE 6. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JANUARY 19 THROUGH JUNE 1982).



VERY
NOT ...
STARTING LATE JAN
65K SPIKE 22 DEC, RE
TO 15K 29 DEC

RET 211695

FIGURE 7. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1982 THROUGH JUNE 30, 1983).



WET DEC

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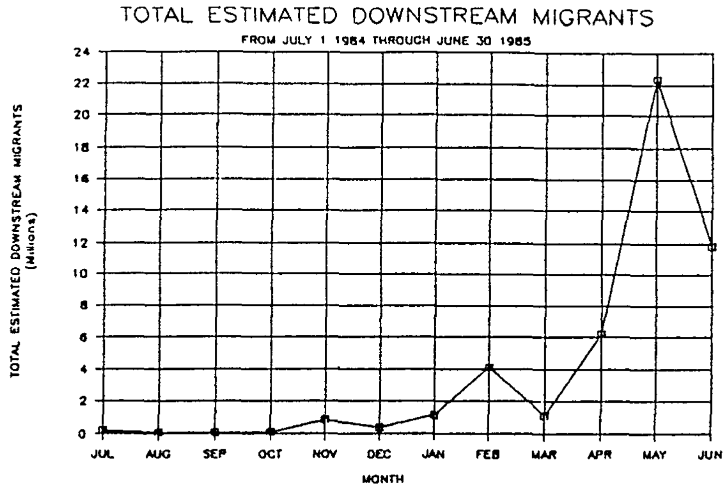
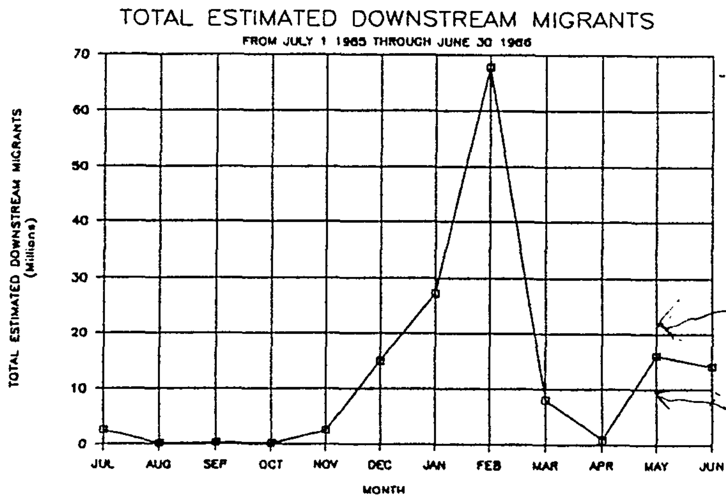
FIGURE 8. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1983 THROUGH JUNE 30, 1984).



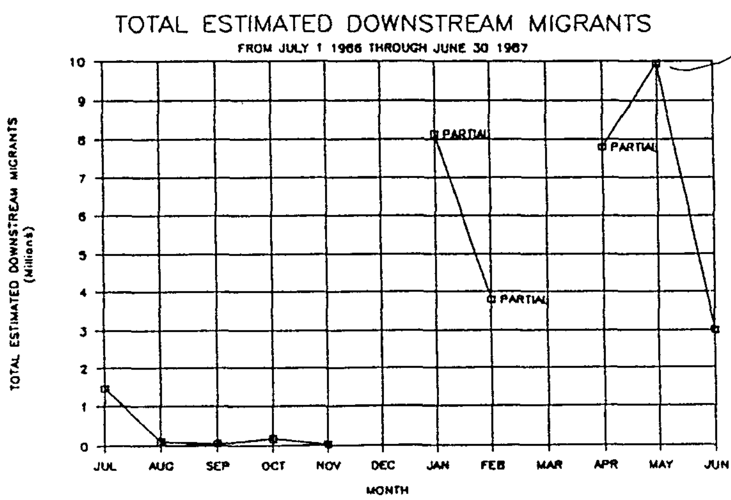
DRY
(WET FALL)
1984

FIGURE 9. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1984 THROUGH JUNE 30, 1985).



V. wet FEB, MAR.
1984

FIGURE 10. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1985 THROUGH JUNE 30, 1986).



DRY
(PULSE TO 32,000 [illegible] IN MARCH)
1967

FIGURE 11. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1986 THROUGH JUNE 30, 1987). PERIODS OF NO ESTIMATES OR PARTIAL ESTIMATES OCCURRED WHEN THE DAM GATES WERE RAISED.

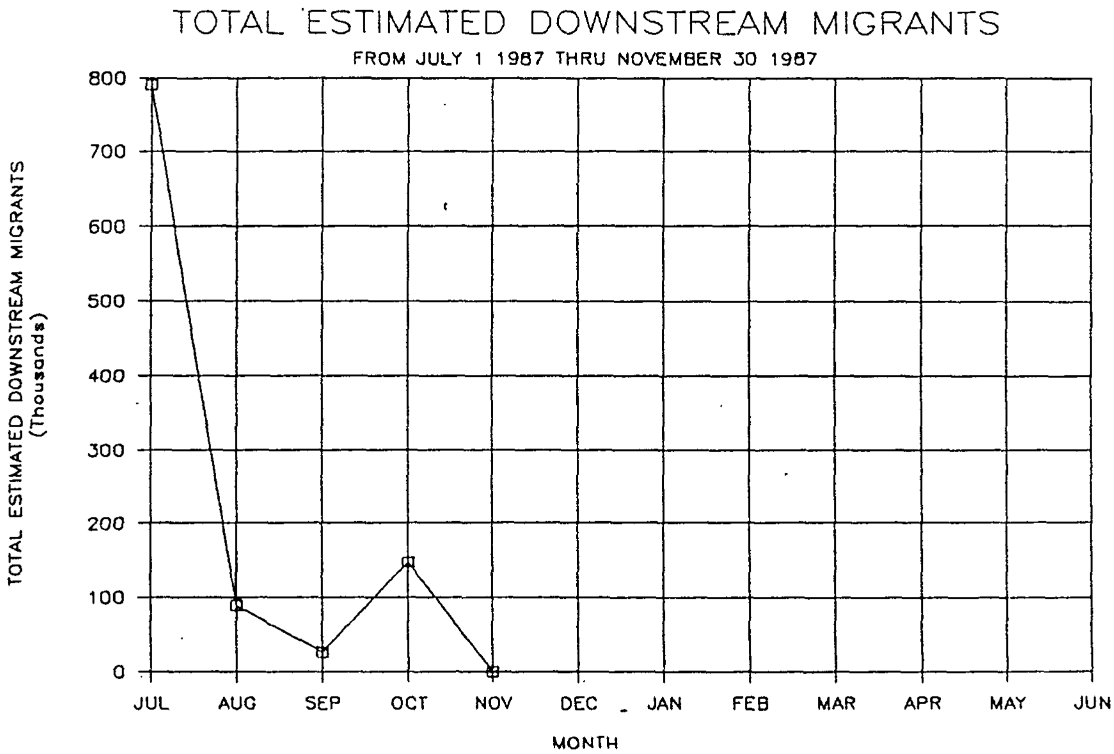


FIGURE 12. ESTIMATED MONTHLY TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (JULY 1, 1987 THROUGH NOVEMBER 30, 1987).

The timing of the peak downstream migration past Red Bluff varied substantially depending on the type of water year. For example, during the wet year of 1982-1983, most downstream migration occurred in the winter (January) whereas, in the dry year of 1984-1985 most downstream migration occurred in the spring (May) (Figure 13).

Figures 14 - 20 show the mean sizes and size ranges of downstream migrants at RBDD during each weekly sampling period. Appendix III Tables 1 - 12 give the daily data on fish sizes. These data show that fry-sized salmon (30-40 mm) and smolt-sized salmon (>80 mm) migrate past RBDD every month of the year.

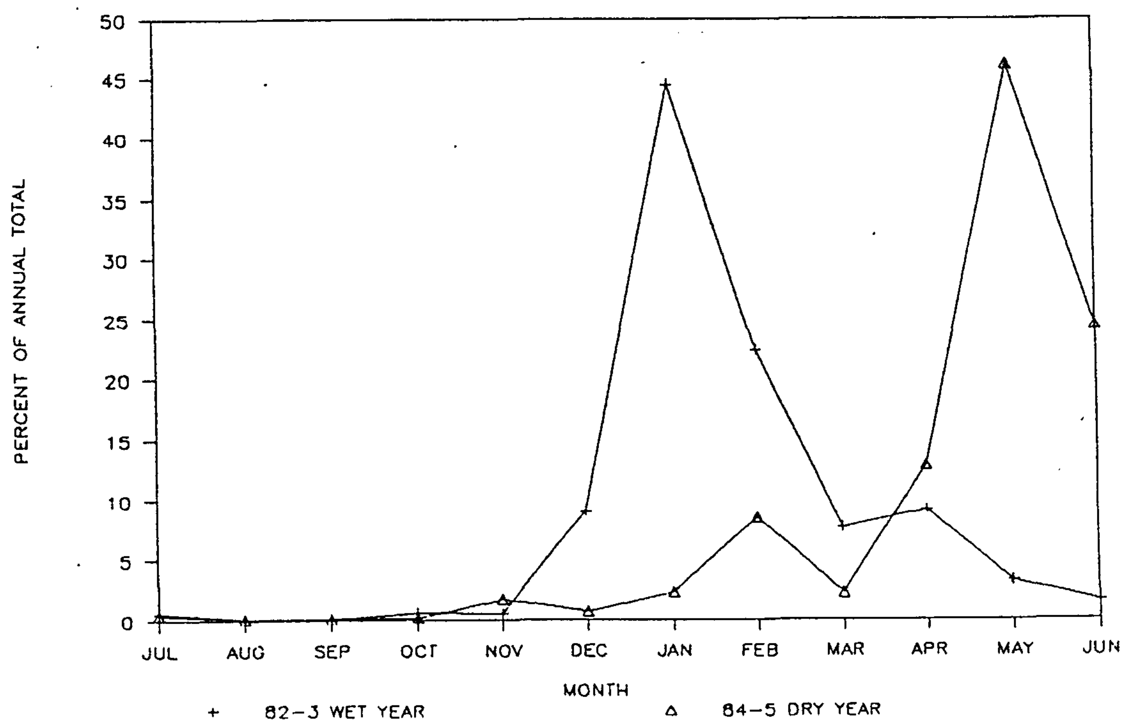


FIGURE 13. ESTIMATED MONTHLY PROPORTION OF ANNUAL TOTAL NUMBER OF DOWNSTREAM MIGRANT CHINOOK SALMON APPROACHING RED BLUFF DIVERSION DAM (1982-1983 WET YEAR; 1984-1985 DRY YEAR).

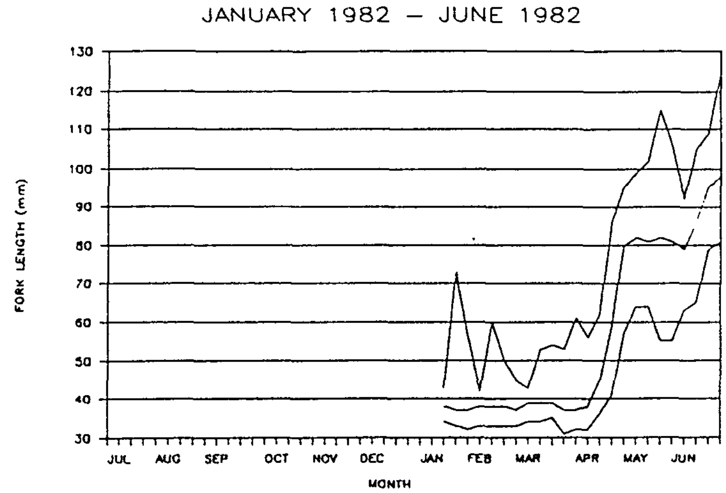


FIGURE 14. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JANUARY THROUGH JUNE 1982).

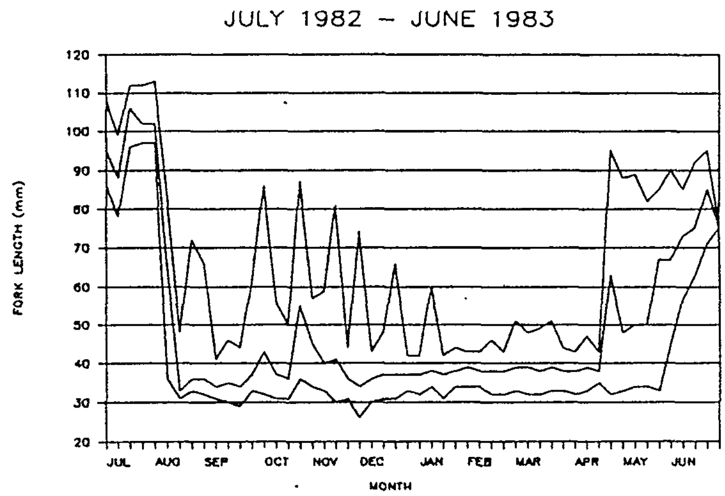


FIGURE 15. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1982 THROUGH JUNE 1983).

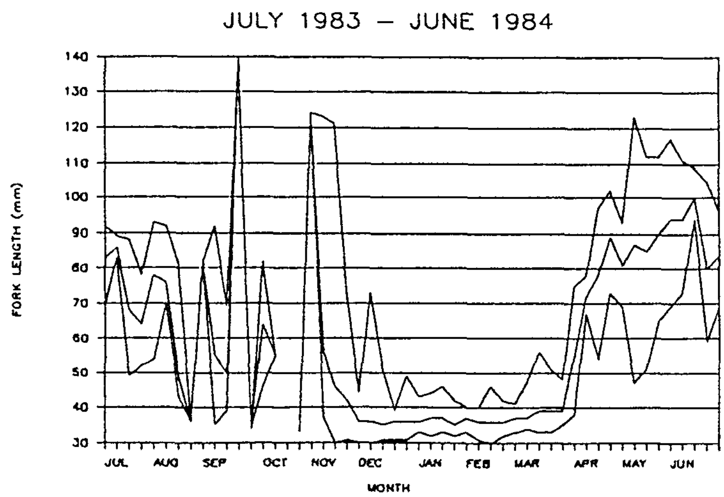


FIGURE 16. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1983 THROUGH JUNE 1984).

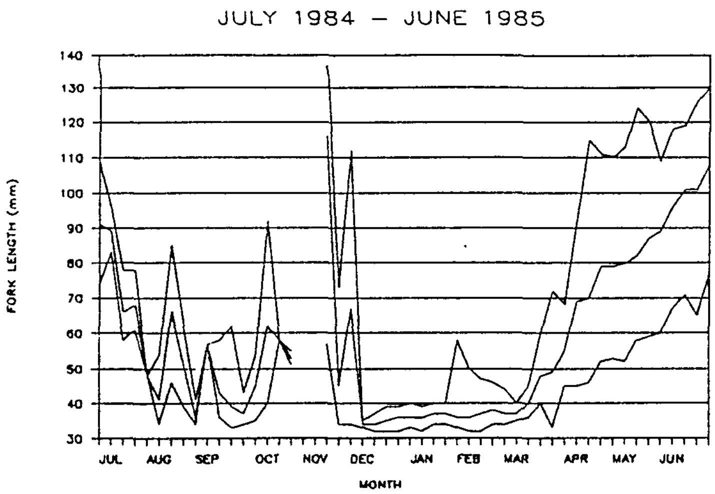


FIGURE 17. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1984 THROUGH JUNE 1985).

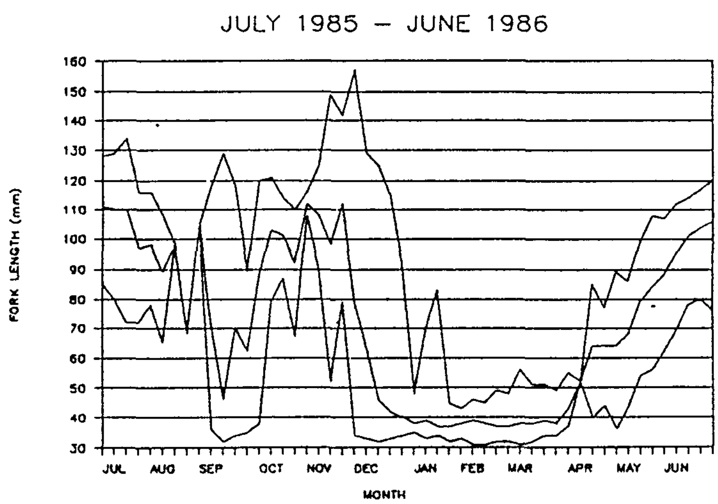


FIGURE 18. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1985 THROUGH JUNE 1986).

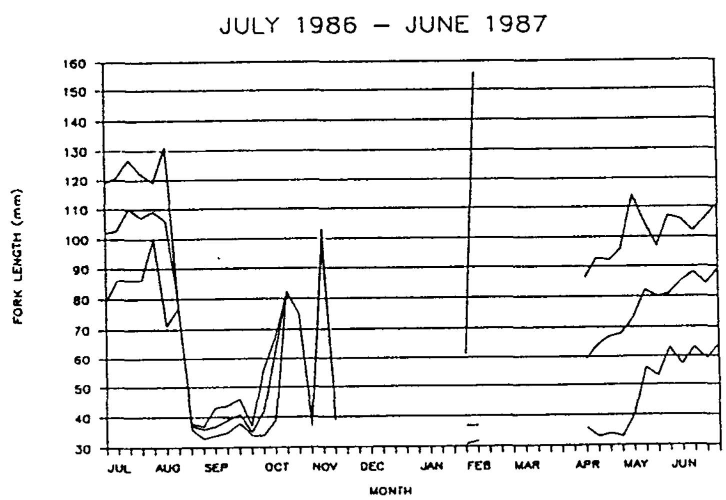


FIGURE 19. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1986 THROUGH JUNE 1987). PERIODS OF NO DATA COLLECTION OCCURRED WHEN THE DAM GATES WERE RAISED.

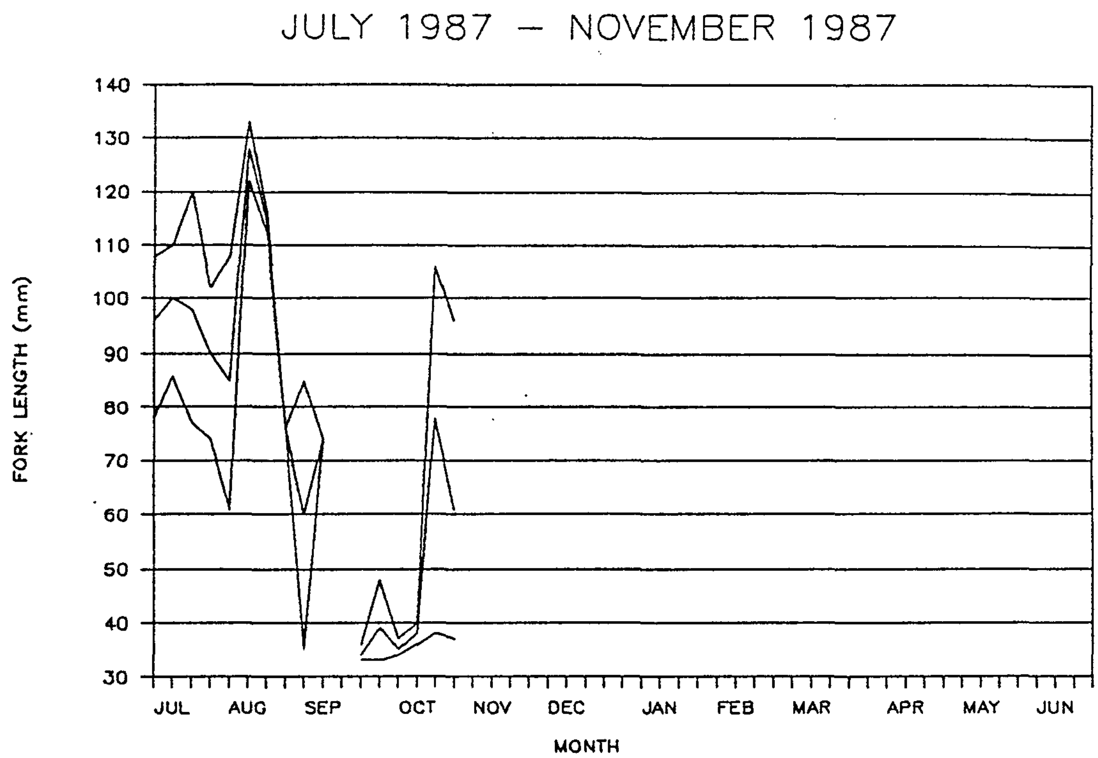


FIGURE 20. MAXIMUM, AVERAGE, AND MINIMUM FORK LENGTHS (MM) OF DOWNSTREAM MIGRANT CHINOOK SALMON AT RED BLUFF DIVERSION DAM. FIGURES ARE WEEKLY AVERAGES. (JULY 1987 THROUGH NOVEMBER 1987).

C-045855

Mortality

Entrainment

The total numbers of juvenile chinook salmon entrained through the T-C Canal headworks louvers from January 19, 1982 through November 29, 1987 are given in Table 3.

Table 3. Total number of juvenile chinook salmon entrained through the Tehama-Colusa Canal headworks louvers, January 19, 1982-November 29, 1987.

Time Period	Downstream Migrant Indices: Total Number Chinook Salmon Entrained	Downstream Migrant Indices: Total Chinook Salmon Approaching RBDD	Percent Total Downstream Migrants Entrained
January 19, 1982-June 30, 1982	434,100	52,981,000	0.81
July 1, 1982-June 30, 1983	614,500	60,451,000	1.02
July 1, 1983-June 30, 1984	182,900	21,762,000	0.84
July 1, 1984-June 30, 1985	179,500	48,501,000	0.37
July 1, 1985-June 30, 1986	594,000	155,361,000	0.38
July 1, 1986-June 30, 1987	204,500	34,547,000 1/	0.59 1/
July 1, 1987-November 29, 1987	2,100	1,055,000	0.20
Total (January 19, 1982 - November 29, 1987)	2,211,600	374,658,000 1/	0.59 1/

1/ Incomplete estimate; no sampling occurred from December 2, 1986 through January 25, 1987 and from February 5, through April 5, 1987 while RBDD gates were raised.

Although all downstream migrant salmon entrained through the T-C Canal headworks louvers are not killed, the assumption that all are killed is useful in estimating maximum possible mortality of all downstream migrants at RBDD due to entrainment. Comparison of the total numbers entrained with the total

C-045856

estimated number of downstream migrants approaching RBDD (index) for all sampling periods combined indicates a maximum loss of 0.59 percent (Table 3). This percentage is relatively small but the numbers of fish are substantial. Actual losses could be considerably less because large numbers of those fish entrained likely make it back out to the Sacramento River via the dual-purpose canal to the single-purpose channels to Coyote Creek.

During each year of our sampling, the highest rate of entrainment consistently occurred at night (Table 4). In most cases, the relatively high daytime entrainment rates corresponded to periods of very high river turbidity.

Table 4. Mean daily entrainment of juvenile chinook per hour through the Tehama-Colusa Canal headworks louvers for day and night sampling from January 19, 1982 through November 29, 1987.

Time Period	Day	Night
January 19, 1982-June 30, 1982	107	151
July 1, 1982 - June 30, 1983	77	91
July 1, 1983 - June 30, 1984	15	29
July 1, 1984 - June 30, 1985	11	30
July 1, 1985 - June 30, 1986	69	99
July 1, 1987 - June 30, 1987	3 1/	10 1/
July 1, 1987 - November 29, 1987	0.3	0.9

1/ Does not include the January 26-February 4, 1987 sampling period when entrainment problems occurred at the T-C headworks.

Direct Injury

Dam Gate Mortality. A total of 33 tests were conducted to determine the mortality rate of downstream migrant salmon caused by physical injury in passing under the RBDD gates. The methods used to determine these mortality rates are described in detail in Appendix I. Twenty-three tests were conducted on gate No. 1 1/ and 10 tests were conducted on gate No. 11 (the sluiceway gate).

Based on these tests, an estimated mortality rate for those fish passing under gate No. 1 was 1.3 percent and for fish passing under gate No. 11 was 0.5 percent with an overall mean mortality of 1.1 percent. Each of the test results are given in Appendix II Tables 2 - 4. These estimates should be considered as maximums because in instances when a control group mortality rate was higher than the corresponding experimental group mortality rate (an apparent "negative rate"), we assumed an adjusted differential mortality rate of zero; this adjustment would bias the overall mortality estimate high. If such "negative mortality rate" values are incorporated, the resulting overall mortality rate would appear to be zero. Therefore, we estimate overall mortality of downstream migrant salmon due to physical injury in passing under the RBDD gates to be within the range of 0 to 1.1 percent with the actual value probably closer to zero.

Because of the large number of replications (33) for this evaluation, we are confident that mortality caused by direct injury to downstream migrants passing under the RBDD gates is negligible and does not warrant further concern or investigation.

1/ Results of tests conducted on Gate No. 1 were assumed to be indicative of conditions for all 10 overflow weir gates on RBDD.

Fish Bypass System Mortality. A total of 34 tests were conducted to determine the mortality rate of downstream migrant salmon caused by physical injury in passing through the fish louver bypass system. The methods used to determine the mortality rates are described in detail in Appendix I.

Based on these tests, an estimated mortality rate for those fish passing through the bypass system was 4.1 percent. Each of the test results are given in Appendix II Tables 5 - 7. This estimate should be considered as a maximum estimate because in instances when a control group mortality rate was higher than the corresponding experimental group mortality rate (an apparent "negative rate"), we assumed an adjusted differential mortality rate of zero; this adjustment would bias the overall mortality estimate high. If such "negative mortality rate" values are incorporated, the resulting overall mortality rate would appear to be 1.6 percent. Therefore, we estimate overall mortality of downstream migrant salmon due to physical injury in passing through the fish louver bypass system to be within the range of 1.6 to 4.1 percent. For the duration of the study, these losses represent 0.10 percent to 0.24 percent of all downstream migrants passing the dam.

Although the fish mortality rate due to physical injury in passing through the bypass system is small, there is cause for concern because millions of downstream migrants pass through the system each year. This concern prompted a closer examination of the bypass system during the course of the Fish Passage Program.

In conducting our tests, at least one of the five bypass pipes appeared to have restricted flow which indicated an obstruction inside the pipe. A visual examination of the one bypass pipe interior revealed considerable accumulation of debris against three plate steel vanes welded to the inside of the pipe. Apparently, shortly after construction of the fish bypass system, hydraulic engineers required accurate measurements of flow through each of the five pipes and installed the vanes as an add-on to improve the accuracy of their water velocity measurements by reducing turbulence in the pipes. At our request, the Bureau removed all 15 vanes from the five bypass pipes. Although we did not assess mortality of fish before and after removal of the vanes, it is reasonable to assume that their presence along with debris likely contributed to direct injury mortalities.

A tremendous amount of air entrainment occurs in the existing fish bypass system. The air creates highly noticeable surging and turbulence of water passing through the pipes. Excessive turbulence throughout the bypass system likely stresses the juvenile salmonids, increases the likelihood of their abrasion inside the bypass facility, and could contribute to direct injury mortality. Based on many hours of underwater observations, air and extreme turbulence at the bypass exit created noticeable disorientation of juveniles exiting the bypass terminal box and increased their susceptibility to predation by squawfish (discussed in the Predation section). Despite several attempts by the Bureau, air entrainment could not be eliminated and continues to occur.

During the first year of the Fish Passage Program, Service divers made an additional noteworthy underwater observation at the bypass terminal box. Adult salmon carcasses were seen wedged against the four-inch spaced vertical steel grates on the terminal box. In addition, apparently attracted by the high velocity water, dozens of salmon were observed inside the terminal box after they had obviously wiggled through the 4-inch spacing of the vertical trash rack grates. Many of those salmon inside the terminal box had fungus on the sides of their bodies, presumably resulting from skin abrasion as they entered the structure. Besides the obvious concern for the direct immediate mortality that may occur at the 4-inch vertical grates, there was concern that those salmon entering the structure may not escape and eventually die, decay, and wash back out into the river having never spawned. Even if the adult salmon could escape from the structure, it was possible that those fish would suffer prespawning mortality resulting from abrasion on the grates when they entered and exited the structure. The significance of this was that adult salmon migrate past RBDD every month of the year, so the structure likely killed an unquantified number of adult salmon year-round since its initial operation in 1966.

After reporting the observations of adult salmon in the bypass terminal box, the U. S. Bureau of Reclamation removed every other vertical grate on the structure which increased the effective openings to about 8 inches. The reason for such an action was to allow salmon to move in and out of the structure at will without suffering skin abrasion or gilling, yet still maintain the structural integrity of the terminal box. Service divers subsequently conducted an evaluation of the effectiveness of that measure through underwater observations and by tagging fish inside the structure and concluded the problem was eliminated.

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Delay in Dam Passage

We used radio-telemetry to investigate the existence, nature, and extent of downstream migration delays caused by RBDD for juvenile steelhead trout and chinook salmon from May 1984 to April 1988 (see Appendix I for Methods).

During May 1984, a preliminary release of eight juvenile steelhead with surgically implanted radio transmitters was conducted. These fish averaged 241 mm in fork length and were released 3.3 miles upstream from the dam during river flows ranging from 8,000-9,400 cfs. Four general behavior patterns occurred after their release in Lake Red Bluff: 1) three steelhead moved immediately downstream to the dam, milled around in the vicinity of partially-opened spill gates, and passed the dam within 13 hours to several days; 2) one steelhead moved downstream to the dam within two days after its release but did not pass for two weeks, after which its radio-tag signal transmission ceased; 3) two steelhead moved downstream after release but never reached the dam before the radio transmission stopped (6-13 days); 4) two steelhead moved upstream as far as 1 mile and remained there until the radio signal transmission ceased (13-19 days).

Two radio-tagged steelhead exhibited obvious signs of distress during the holding period after the tag implant procedure. These fish were not released. Autopsies indicated that injury (ruptured air bladders) occurred during the implant procedure. Although the steelhead released appeared in good condition and showed no aberrant behavior, we modified our technique for the 1985 to 1988 field seasons by using external attachment harnesses described in Appendix I (Methods) to avoid the potential for affecting behaviors caused by injury.

Three radio-tagged juvenile steelhead outmigration trials (21 tagged fish) were conducted during February and March 1985. Low, clear river flows ranging from 5700 to 7200 cfs existed during this period. These steelhead exhibited similar behavior to that observed during 1984. Table 5 summarizes the 1985 results.

Table 5. Results of 1985 radio-tagged juvenile steelhead outmigration trials in Lake Red Bluff (LRB). Fish were released at river mile 246.3.

Date Released	Number Released	Time Released	Mean Fork Length ±S.D. (mm)	Number That Passed Dam	Number Consumed by Cormorants Before Passing Dam	Number With Unknown Fates	Number That Remained in LRB Upstream From RBDD	Number Moving Upstream Out of LRB
2/21/85	9	1330	206 ±17	6	2	0	1	0
3/06/85	7	1300	204 ±20	4	2	1	0	0
03/14/85	5	0915	201 ±20	1	2	1	0	1

Of the eleven steelhead that passed the dam, ten migrated past the dam within 1 to 2 days while the other steelhead took between 6 and 7 days to pass. Two of the steelhead that passed appeared to mill around in front of the dam for several hours prior to passing. One steelhead in the February 21, 1985 release group migrated from RM 245.3 (Antelope Boulevard Bridge) to RBDD in 2 hours, only to move back upstream approximately 0.75 miles and remained there until the tag ceased transmitting 15 days later. Upstream movement from the release site was observed for one fish, a behavior also noted in 1984.

The most significant result of these outmigration trials was the observed predation on radio-tagged steelhead by double-crested cormorants

(Phalacrocorax auritas), a deep-diving, efficient predator of fishes. Twenty-nine percent (n=6) of the radio-tagged steelhead in the release groups were confirmed to have been eaten by the cormorants. All steelhead predation occurred during their migration through Lake Red Bluff. Two cormorants were actually tracked with the radio signal originating from the birds. The other four steelhead radio-tag signals were located in the water at the base of a large snag used as a roost by the cormorants. Since the signals never changed locations, we assumed the birds had eaten the steelhead and either regurgitated or defecated the tag at the roost.

Several factors may account for this observed predation. First, the very low and clear late-winter and spring river flows experienced during 1985 provided ideal conditions for the cormorant population residing along the length of Lake Red Bluff to prey on outmigrating salmon and steelhead smolts. The pool-like habitat of Lake Red Bluff is an attractive habitat and fishing area for cormorants. Second, the small radio-transmitters on the backs of the steelhead were yellow and silver in coloration which may have enhanced the fishes' visibility to the fishing cormorants. Third, the naivete of the hatchery-reared steelhead to predators may have increased the radio-tagged steelhead's vulnerability to cormorant predation. The two latter factors notwithstanding, the results indicate that under low, clear river flows, bird predation on downstream migrant steelhead in Lake Red Bluff may be substantial.

During the 1986 to 1988 field seasons, we focused our efforts on measuring the migration rate through Lake Red Bluff to RBDD and the delay until passage once RBDD is encountered by downstream migrant salmonids. We included both yearling steelhead and yearling chinook salmon of appropriate tagable size (190-300 mm fork length). Outmigration behavior was observed under a variety of conditions: with the RBDD gates in, with the RBDD gates out during non-irrigation periods, during river flows ranging from 4,000 to 103,000 cfs, and throughout the winter and spring seasons (the months November through May). Complete data for these outmigration trials are tabled in Appendix II Table 8.

Migration times through Lake Red Bluff from a point approximately 2.5 miles upstream down to RBDD tended to be greatest during low river flows (<10,000 cfs) for both juvenile salmon and steelhead (Figures 21 & 22); however, steelhead exhibited considerable variation in migration time at lower flows that appears to be related to season. The greatest steelhead migration time (115 hours) and variations in migration time occurred during the months of May and December (Appendix II Table 8). During these trials, environmental conditions and physiological conditions of the fish may have combined to cause reduced downstream migration tendencies. Hallock et al. (1961) noted that the primary downstream migration of juvenile steelhead in the upper Sacramento River occurred during late winter and early spring seasons. The months of May and December may fall outside this period.

Overall, mean migration times for juvenile chinook salmon were short and the range was relatively narrow (0.5-5.2 hours). Migration times did not appear greatly affected whether the dam gates were in or out of the water. Similarly, mean delays in passage after arrival at RBDD with the dam gates in the water were generally short (<40 minutes) but were observed as long as 2.2 hours (Figure 21). The high latter value was observed for a group of three juvenile salmon released April 27, 1988 of which one salmon that arrived at the dam during daylight hesitated for 5.4 hours before passing. However, our

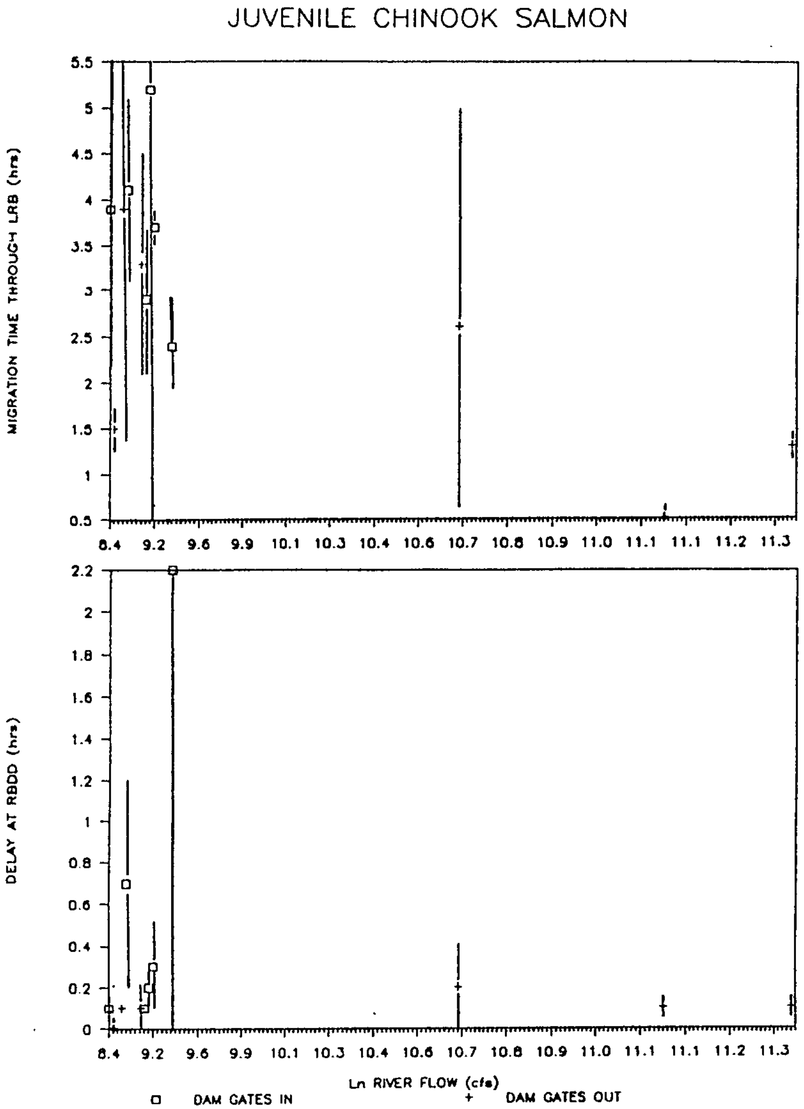

Figure 21. Mean times (± 1 s.d.) of migration through Lake Red Bluff (LRB) and delay at Red Bluff Diversion Dam (RBDD) for radio-tagged yearling chinook salmon as related to flow past RBDD during 1987-1988.

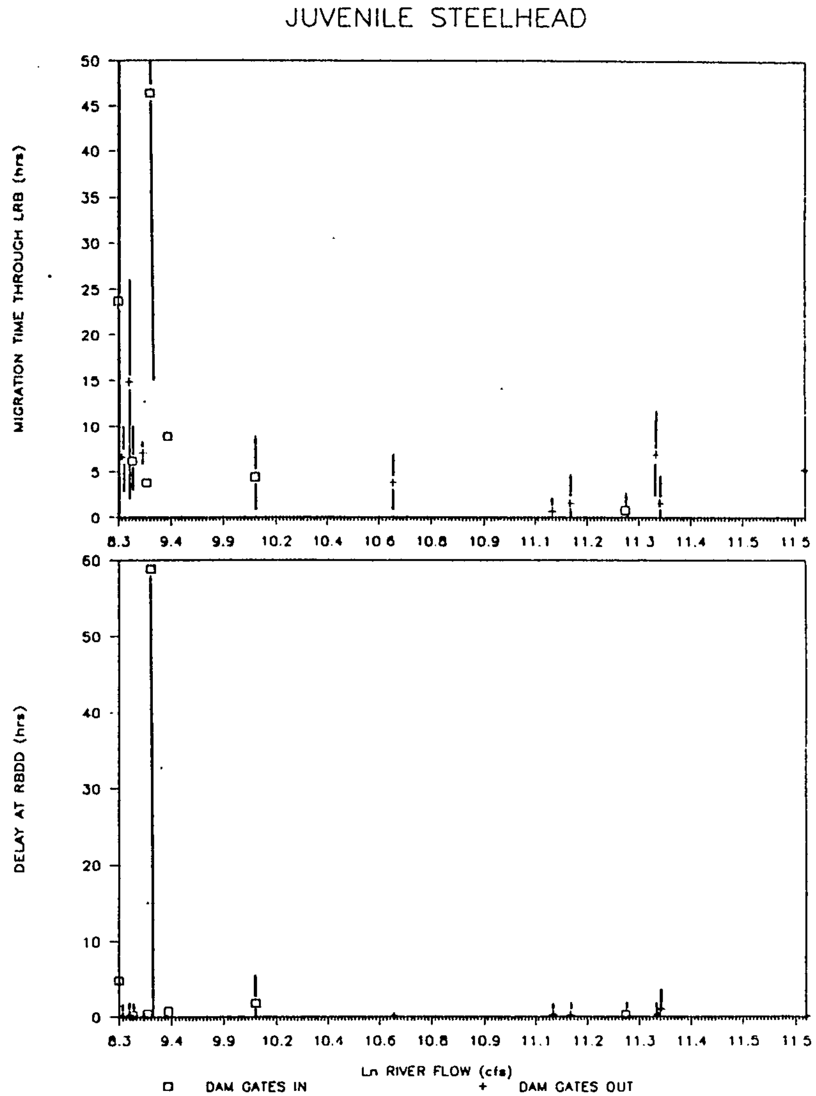

Figure 22. Mean times (± 1 s.d.) of migration through Lake Red Bluff (LRB) and delay at Red Bluff Diversion Dam (RBDD) for radio-tagged yearling steelhead trout as related to flow past RBDD during 1987-1988.

observations of individual radio-tagged juvenile salmon indicated that their dominant behavior pattern was to remain at or near the release site (RM 246) in a deep pool during daylight, then to initiate active downstream migration near or shortly after sunset, encountering RBDD at night, and passing the dam with little hesitation. Night passage also predominated for juvenile chinook and coho salmon and steelhead trout at John Day Dam on the Columbia River (Stuehrenberg and Liscom, 1983; Giorgi et al., 1985). Juvenile salmon primarily passed through those partially opened RBDD gates spilling the greatest percentage of spill. Movement to and past the dam was direct and few hesitant or veering maneuvers were observed.

These observations of radio-tagged yearling chinook salmon smolt migration behavior through Lake Red Bluff substantiate the results of day and night trawling surveys in Lake Red Bluff for subyearling chinook salmon smolts after release from Coleman National Fish Hatchery. Figure 23 shows the outmigration pattern of three hatchery releases of salmon as they passed through Lake Red Bluff during 1984, 1985, 1986. The narrow peaks in trawl catch per unit effort consistently occurred over approximately 4-hour periods in all three years and indicate that migration rates through Lake Red Bluff are relatively short.

As with migration time, juvenile steelhead exhibited a wider range in delay before passing RBDD with the gates in the water than did juvenile chinook salmon (Figure 22). Delay was negligible at all river flows with the dam gates out of the water. The longest observed mean delay for passing the dam with gates in the water was 59 hours for two juvenile steelhead released in a group of five on May 28, 1987. The other three steelhead remained (or residualized) in Lake Red Bluff for periods of 3 to 8 days after which radio

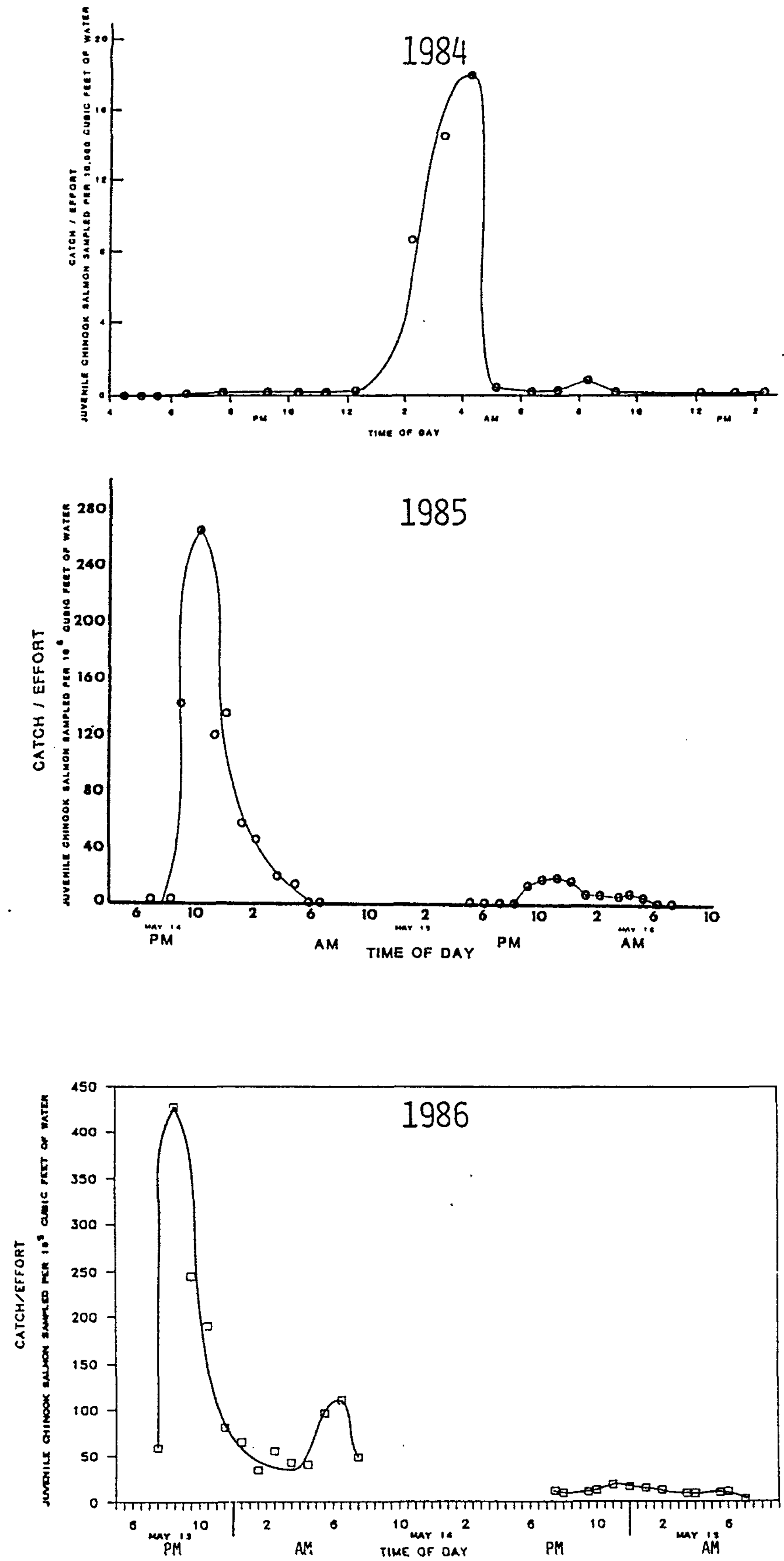

Figure 23. Outmigration pattern of subyearling chinook salmon released from Coleman National Fish Hatchery as they passed through Lake Red Bluff during May releases in 1984-1986 determined by diel trawling surveys.

contact was lost (likely due to failing, short-lived transmitter batteries). This behavior of residualizing in Lake Red Bluff was observed only for steelhead, occurred for fish migrating down the reservoir that stopped and took up holding positions or apparently set up feeding territories (since movement was limited to localized areas for several days), and occurred in fish that first migrated to RBDD but returned back upstream and held at various locations in Lake Red Bluff.

Although steelhead were observed to remain in the Lake Red Bluff section of the river, both during periods when RBDD gates were in and out of the water, it was most predominant when the dam gates were in the water (Figure 24).

The observed increase in residualization behavior of juvenile steelhead in Lake Red Bluff is cause for concern as to their survival. First, as discussed previously, predation by birds as well as predaceous fishes, may be higher in the pool-like conditions of the reservoir than in other areas of the river. Steelhead remaining for extended periods in the reservoir are at higher risk to these types of predation. Second, because of the discrete timing of the smolting cycles in juvenile anadromous salmonids, any delays in downstream migration may cause asynchrony in the arrival at seawater and the physiological ability of the fish to acclimate and survive in the sea. Third, delays in downstream smolt migrations can cause energy reserve depletions which can severely effect seawater acclimation (Rondorf et al. 1983).

Direct observation of individual steelhead behavior upon encountering RBDD indicated that the dam is a greater impediment to downstream steelhead passage than it is for juvenile salmon. Steelhead exhibited a significantly greater degree of hesitant behavior prior to passing the dam than did salmon. These behavior patterns were dominated by steelhead moving directly toward

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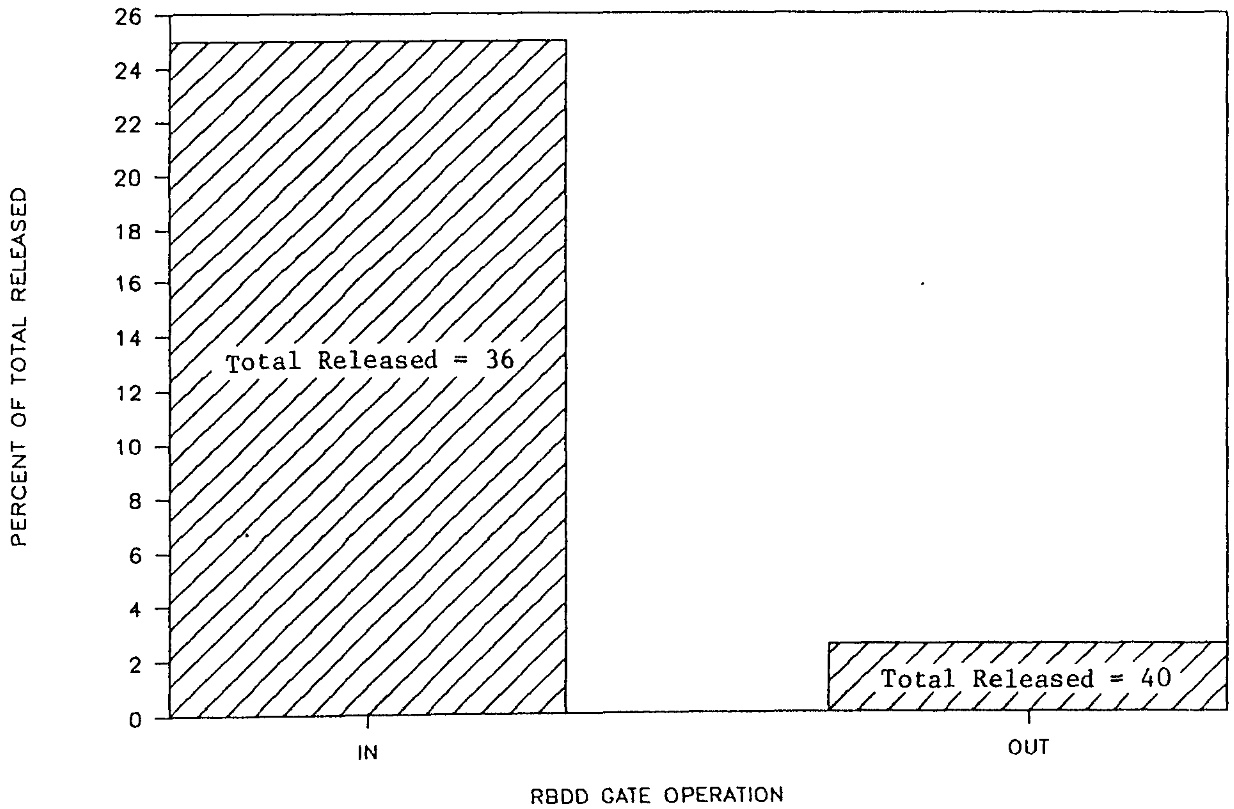

Figure 24. Frequency of remaining in Lake Red Bluff for three days or longer (residualization) with the dam gates in and out of the water during 1986 - 1988 for radio-tagged yearling steelhead trout.

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open spill gates upon first encounter only to veer along the face of the spill gates and move back upstream. Several circuits of this pattern were made by steelhead before they would pass beneath an open gate or move back upstream. Frequently, steelhead would spend several hours in this curcuitous movement prior to passing the dam (with gates in the water) at flows up to 22,000 cfs. This behavior may have been more predominant in steelhead due to their generally larger size than the salmon used in this study. The steelhead may have been able to overcome the pull of the underspills. This observation may also be attributed to a potentially inherent behavioral reluctance of juvenile steelhead to pass under the spill gates. This behavior may provide justification for utilization of the new gate 11 surface spill flip-gate to improve juvenile steelhead passage at RBDD.

Predation

The best estimates of overall mortality to downstream migrant salmon at Red Bluff Diversion Dam were developed during the spring of 1984. During other years, the experiments could not be conducted due to conflicts with other fish marking programs within the river system or the experiments did not result in sufficient sample sizes to derive meaningful mortality estimates. The methods for the 1984 total mortality estimate are described in detail in Appendix I and the results of the tests are summarized in Table 6.

We examined the other possible sources of downstream migrant mortality, and by process of elimination, the overall high losses of juvenile salmon at RBDD must be attributed to predation. These overall high mortality rates are further substantiated by Hallock's (1983) study where he found mortality of juvenile fall chinook to range from 29 to 77 percent. Based on our findings, the maximum possible losses due to causes other than predation (i.e., entrainment, direct injury, and delay in the reservoir) could only be several percent, leaving predation as by far the dominant contributor to mortality.

Table 6. Mortality estimates of juvenile chinook salmon released during the day and night above Red Bluff Diversion Dam.

	Differential Mortality Estimate (%)		
Release Time	Point	High 1/	Low 1/
April 26, 1984 (Night)	16	32	0
May 14, 1984 (Day)	55	69	39

1/ High and low estimates based on a 95% confidence interval for the proportion of recoveries of the group released above the dam within the total recovery sample.

A large number of surface and underwater observations during the five-year program convinced us that squawfish are the primary predator on juvenile salmon at RBDD. This assumption was further substantiated by periodically examining stomach contents of squawfish following juvenile salmon releases during various phases of the program. Limited observations and sampling also indicated that juvenile steelhead are susceptible to both piscine and avian predation (eg. cormorants). A comprehensive, detailed assessment of squawfish predation at the dam and in Lake Red Bluff was beyond the scope of the Fish Passage Program, however, we believe such an assessment is critically important in order to develop solutions to the problem.

Predation on juvenile salmon by squawfish is particularly evident in the spring months when the peak upstream migration of squawfish at RBDD occurs (Figure 25) and large numbers of downstream migrant salmon are passing the dam

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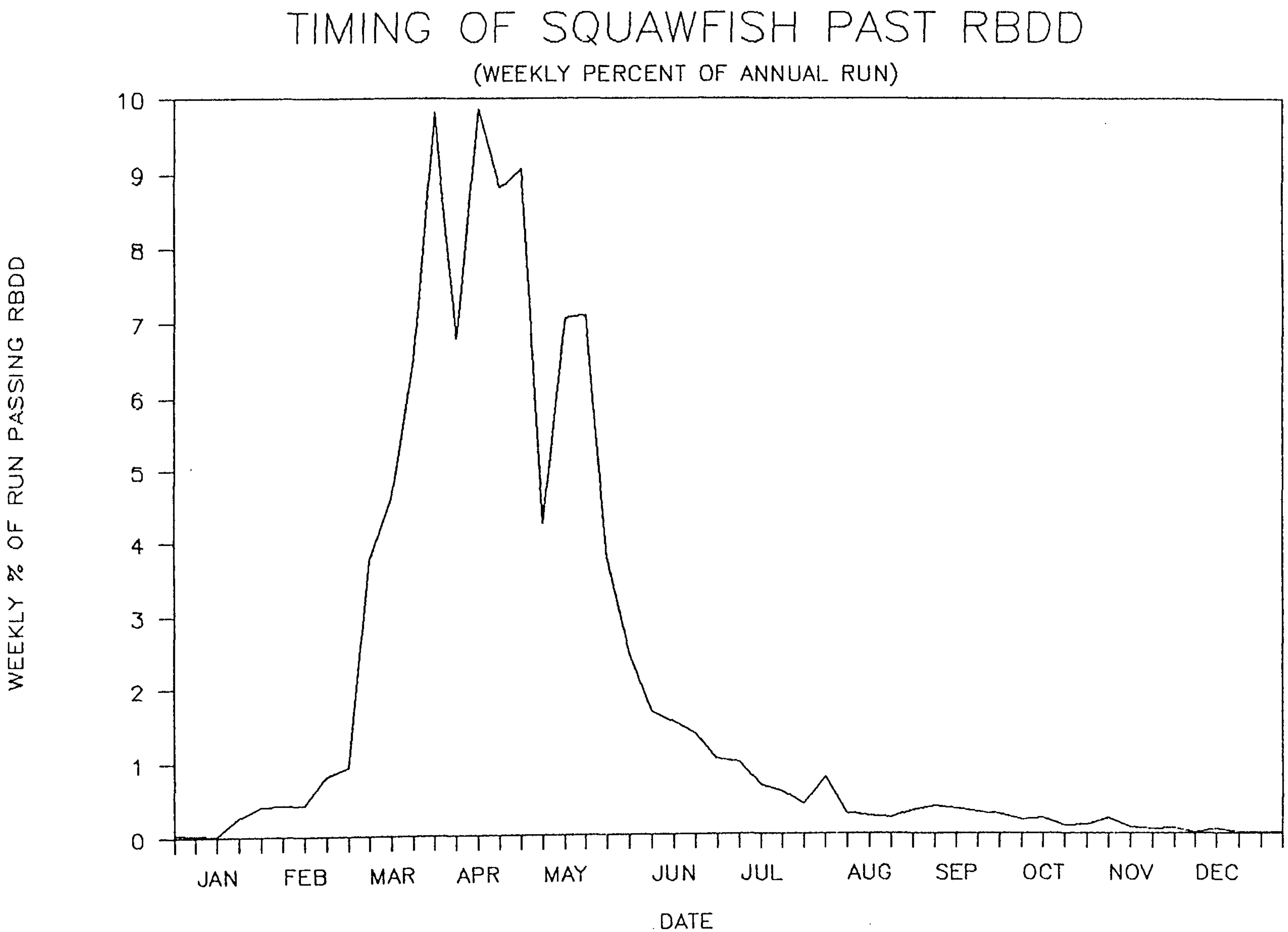

FIGURE 25. TIMING OF SQUAWFISH PAST RED BLUFF DIVERSION DAM (RBDD) - WEEKLY PERCENT OF ANNUAL RUN BASED ON COUNTS IN 1969 - 1972 AND 1978 - 1984.

(Figures 6 - 11). Extremely active predation was displayed during the spring of 1985 when thousands of squawfish accumulated downstream of the dam coinciding with the peak downstream migration of salmon for that year (Figure 13).

During the initial year of the program, we expressed concern to the Bureau that the high-intensity sodium vapor lights on the dam at night may create "daytime predation conditions". The Bureau agreed to turn off these lights at night to reduce that hazard and based on observations and limited sampling, it appears this measure was effective in reducing night-time predation. A more intensive evaluation would be necessary to make definite conclusions.

Based on surface and underwater (SCUBA diving) observations, downstream migrant salmon are considerably disoriented after passing under the RBDD gates or through the T-C Canal fish bypass facility. This disorientation makes the emigrants highly vulnerable to predators. Predation by seagulls, in addition to predation by squawfish, was also evident. Although it was not specifically evaluated in this program, we believe the measure of raising the dam gates during the non-irrigation season reduces predation losses because downstream migrants are not disoriented in dam passage and predator concentrations are dispersed.

Underwater observations of juvenile salmon exiting the bypass terminal box were particularly interesting. These fish were noticeably disoriented as they entered the river and darted in a multitude of directions. Most of the young salmon swimming out into the main water column of the river or darting toward the surface were quickly detected and consumed by squawfish. Those juvenile salmon darting to the bottom of the river channel and back toward the shallower areas on the river's edge found protection among rocks and boulders and largely avoided detection and predation by squawfish. Individual juveniles taking the latter route quickly schooled with other juveniles among the boulders and became very wary when divers neared. Squawfish were extremely effective in preying on those juvenile salmon swimming in a location more than several feet off the riverbed and, in particular, on those juveniles oriented in the water column above the squawfish. In these cases, the squawfish were observed striking the young salmon extremely fast with very few misses. Conversely, squawfish were not nearly as effective in preying upon young salmon located near the riverbed or river's edge when rocks and boulders were present and particularly when the juvenile salmon had schooled. In these locations, the speed at which squawfish struck at the juveniles did not appear as fast as noted out in the main water column and there was a great deal more failed attempts at feeding.

Overall, because of the severity of the predation losses, and because of the presence of predators and downstream migrants at the dam every month of the year, we believe future efforts to reduce predation losses are of paramount importance in improving downstream migrant survival at RBDD.

ADULT SALMONID PASSAGE

Delay and Blockage

The release and monitoring of radio-tagged salmon below RBDD during the first three years of the program provided further substantiation of the problem of delay and blockage of salmon at the dam originally described by Hallock et al. (1982). The blockage of migrating salmon, particularly the late-fall, winter, and spring runs is of considerable concern. More than one-third of the radio-tagged late-fall and 40 percent of radio-tagged winter-run chinook were blocked by the dam during our study and Hallock et al.'s (1982) study (Table 7).

Table 7. Behavior of radio-tagged adult chinook salmon at Red Bluff Diversion Dam.

Run	Number of Radio-Tagged Salmon That Approached RBDD 1/		Percent Blocked by the Dam		Mean Delay Below RBDD 2/ (Hours)	
	This Study	Hallock et al. (1982)	This Study	Hallock et al. (1982)	This Study	Hallock et al. (1982)
Fall	65	20	8 (n=5)	15 (n=3)	90 (1-983) (n=60)	84 (24-360) (n=17)
Late-Fall	19	17	37 (n=7)	35 (n=6)	78 (5-197) (n=12)	94 (24-168) (n=11)
Winter	32	14	44 (n=14)	43 (n=6)	125 (2-854) (n=18)	437 (24-960) (n=8)
Spring	28	3	18 (n=5)	33 (n=1)	320 (5-1212) (n=23)	264 (24-528) (n=2)

1/ These numbers include only those salmon whose migration fate was known. It does not include salmon that encountered the dam but whose migration fate is unknown due to failing transmitters or poor registration by a data logger.
2/ From first approach to upstream departure; range in parentheses.

Also of concern is the delay all runs experienced at the dam (Table 7). A possible indirect loss of young salmonids through reduced productivity could be caused by excessive delay of maturing adult salmonids below RBDD to the point where spawner fecundity declines (e.g., prespawning mortality, reduced egg viability, spawning in less than optimal habitat, etc.). Salmon blocked at RBDD are forced to spawn in downstream areas which is detrimental to incubating salmon eggs when water temperatures are high (>56^{o}F), as occurs during the summer months when the winter-run spawn (Hallock and Fisher 1985). Thirty-two percent of the variation in delay time for all runs in the study by

Hallock et al. (1982) was attributable to total river discharge at the dam, and statistically correlated with this was operation of the dam and number of spill gates opened. They were able to attribute a statistically significant forty-five percent of the variation in delay time to the percentage spill passing through or adjacent to the fishways (i.e. delay is inversely related to percent spill near fishways). Although Hallock et al. did not experimentally field test these correlations, their results presented strong indication that spill manipulation could potentially produce improvements for salmon passage at RBDD and was the basis for some of our experiments in the Fish Passage Program.

Spill Configuration and Dam Gate Manipulation

Operational studies at dams on the Columbia and Snake River systems for the improvement of salmonid passage served as models for our studies (spill pattern manipulation - Leman and Paulik 1966; spill distribution and fish ladders - Junge and Carnegie 1970, 1972; and Liscom and Monan 1976). Methods used in our study are described in detail in Appendix I.

We radio-tagged 304 adult chinook salmon for use in various RBDD operations experiments during 1984 through 1988; these are broken down by run as follows: fall run (n=130), late-fall run (n=54), winter run (n=69), and spring run (n=51). Some fish could not be distinguished between spring and fall runs due to overlapping migration and spawning periods, consequently we categorized these fish as spring-run chinook. The schedule of assessment of spill and fishway operations for the improvement of upstream salmonid passage that we conducted are shown in Table 8.

Table 8. Schedule for assessments of spill and fishway operations for the Red Bluff Diversion Dam Fish Passage Action Program, 1983-1988.

Study Year	Low Flow Single-crowned Spills	Double-crowned Spills	Short-Term Spill Manipulations	Winter Gates-Raised Operation
1983-84	X			
1984-85	X			
1985-86	X	X		
1986-87	X	X	X	X
1987-88			X	X

Spill Configurations

Our initial objective, i.e., to assess spill crowning as a means of improving upstream salmon passage at higher river flows (>14,000 cfs), was hampered during the course of studies due to unusually low river flows or short periods of high river flows when the dam gates were out of the water (Figure 26). In addition, during some high flow periods experiments were hampered because few salmon were available for radio-tagging (because of depressed late-fall and winter runs). However, we were able to conduct a sufficient number of low to mid-level flow (4,000-12,000 cfs) spill crowning tests to derive information for assessing the usefulness of spill crowning in improving fish passage.

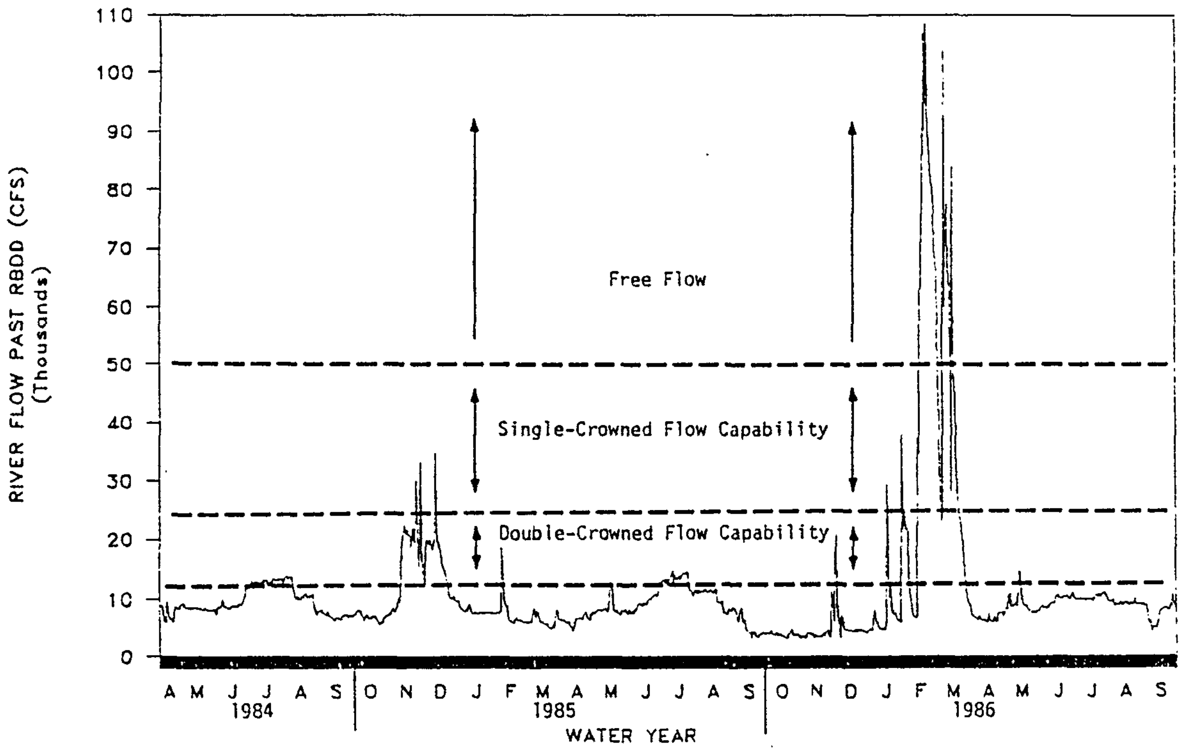

Figure 26. River flows (cfs) past Red Bluff Diversion Dam for the period April 12, 1984 through September 30, 1986. (Data on river flows in excess of 50,000 cfs were obtained from the USGS stream gauge at Bend Bridge). See text for explanation of flow-crowning capabilities.

Between April 1984 and September 1986, a total of 193 salmon in 24 groups were radio-tagged and released three miles downstream from RBDD and exposed to either one of the two experimental crowned spills or a control spill pattern (discharged from nearly uniform gate openings) at the dam. Differences between the experimental spill configurations are presented in Appendix I Tables 1 and 2. Appendix II Table 9 contains experimental release group summaries with dates of release, numbers of radio-tagged salmon, predominant spill configurations, and summary statistics for each of the release groups. The following tables, Table 9 and Table 10, summarize the major findings from those tests.

Table 9. Percentage of radio-tagged chinook salmon blocked at RBDD under experimental and control spill conditions, 1984-1986 (numbers in parentheses are number of salmon encountering the dam).

	Spill Configuration		
Run	Control	Low Flow Single-Crowned Spill	Double-Crowned Spill
Fall	11.1 (n=18)	0.0 (n=18)	10.3 (n=29)
Late-Fall	--	36.8 (n=19)	--
Winter	--	43.8 (n=32)	--
Spring	25.0 (n=4)	22.2 (n=18)	0.0 (n=6)

Table 10. Total delay, in hours, presented as mean ±SE, range, and number of salmon for radio-tagged chinook salmon encountering and passing RBDD under experimental and control spill configurations during 1984-1986.

	Spill Configuration		
Run	Control	Low Flow Single-Crowned Spill	Double-Crowned Spill
Fall	69.6 ± 47.1 (0.8 - 769.4) n=16	91.9 ± 35.4 (2.0 - 551.3) n=18	101.4 ± 49.9 (3.4 - 982.6) n=26
Late-Fall	--	78.4 ± 21.5 (5.0 - 197.0) n=12	--
Winter	--	125.4 ± 46.3 (2.2 - 854.2) n=18	--
Spring	448.9 ± 336.9 (106.5 - 1122.6) n=3	397.7 ± 127.7 (4.9 - 1211.5) n=14	73.2 ± 23.9 (5.3 - 145.9) n=6

Although we were unable to obtain data for all runs of salmon under each spill condition at RBDD, it was quite obvious that the effect of each of the experimental spills was not consistent within or between runs, (i.e. broad ranges in delay time and excessive delays were observed for all spill configurations). Spring-run salmon appeared to respond with shorter delays and a lower percentage dropbacks under the experimental spill configurations, but variation was extreme and numbers of fish were low. This relationship will have to be viewed with caution given the opposite response by fall-run salmon to similar spill configurations. Additionally, due to the extreme amount of variation in delays within test groups and the non-homogeneous nature of the variation between groups, no statistically significant effect on delays could be evaluated.

The conclusion from low flow single- and double-crowned spill configuration tests was that spill crowning in itself, within the standard operating procedure for RBDD does not significantly improve upstream salmonid passage within river discharges of 4,000-12,000 cfs at RBDD. Factors other than, or in addition to, spill configurations were affecting delays of chinook salmon at RBDD.

Winter Gates-Raised Operation

A special measure of raising the RBDD gates during the winter non-irrigation seasons in 1986-87 and 1987-88 was conducted to improve fish passage conditions; principal emphasis was to provide unimpeded winter-run salmon passage to the essential, cooler upriver spawning areas. Ninety-three days of free flow conditions at RBDD (i.e. dam gates entirely removed from the water) were provided during 1986-87 (December 14, 1986 to January 23, 1987; February 9 to April 2, 1987; and April 3 to April 4, 1987). The gates were

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replaced in the water during the late January to February 1987 period to provide irrigation diversions to the Tehama-Colusa and Corning Canals and a second period when the gates were partially replaced in the water during April 2 and 3, 1987. During the winter of 1987-88, the RBDD gates were raised for 68 consecutive days, from December 10, 1987 to February 16, 1988, and for two additional days March 8 and 9, 1988. Periods ranging from 3 to 14 days were associated with complete drawdown of the reservoir and 1.5 to 3 days were associated with refilling the reservoir.

During reservoir drawdown procedures, fish ladders became unpassable when the upstream water surface elevation decreased below 248.25 msl (based on fish counting at the fish ladders). Salmon were completely blocked from migrating past RBDD between the time that the fish ladders became unpassable and the time that salmon could pass beneath the dam gates; these time intervals ranged from three to nine days. From a fish passage standpoint, it would be advantageous to minimize this period of total fish blockage by drawing the reservoir down as rapidly as possible.

Table 11 presents behavioral responses of 15 radio-tagged chinook salmon that encountered the dam during the gates-raising operation (reservoir drawdown) in 1986 and 1987. Two of the 15 salmon were blocked at the dam; the remaining 13 salmon were observed to pass beneath the dam gates with less than 3 feet of hydraulic head differential. Additionally, USBR and USFWS personnel observed salmon immediately upstream from the dam in Lake Red Bluff when approximately 3.5 feet of head differential occurred. So, salmon were able to begin passing beneath the dam gates with a 2.75- to 3.5-foot head differential.

Table 11. Behavioral response of individual radio-tagged chinook salmon encountering RBDD during reservoir drawdown procedures - Winters 1986-87 and 1987-88.

Race	Sex	Date of Arrival	Date and Time Departed Dam	Direction of Departure U/S-Upstream D/S-Downstream	Differential At Departure (Feet)	Total Delay (Hours)
Late Fall	M	12/10/86	12/11/86 - 1532	U/S	2.3	24.28
Late Fall	M	12/10/86	12/16/86 - 0522	U/S	0.5	133.87
Late Fall	M	12/10/86	12/14/86 - 2341	U/S	0.5	103.93
Late Fall	F	12/10/86	12/13/86 - 1220	D/S	0.8	68.25
Late Fall	F	12/10/86	12/11/86 - 1222	U/S	2.3	20.12
Late Fall	F	12/10/86	12/14/86 - 1447	U/S	0.5	94.32
Late Fall	F	01/27/87	02/08/87 - 1239	U/S	2.0	252.53
Late Fall	M	01/28/87	02/08/87 - 2318	U/S	< 1.0	251.27
Late Fall	M	01/28/87	02/08/87 - 1540	U/S	1.8	241.70
Winter	M	01/28/87	02/08/87 - 1134	U/S	2.0	243.43
Winter	F	01/28/87	02/09/87 - 0625	U/S	0.5	274.97
Winter	M	03/31/87	04/03/87 - 1520	U/S	2.75	2.32
Fall	F	12/03/87	12/06/87 - 0231	D/S	5.2	62.30
Fall	M	12/03/87	12/11/87 - 1445	U/S	Gates Pulled	192.10
Late Fall	M	12/03/87	12/13/87 - 0313	U/S	Gates Pulled	216.60

Salmon passage conditions were dramatically improved during the gates-raised periods. Of eleven radio-tagged winter run and nine radio-tagged late fall-run salmon that encountered RBDD with gates out of the water during 1986-87 and 1987-88, no blockage was observed, as compared with an overall 40 percent blockage rate for radio-tagged winter-run (n=43) and late- fall-run (n=25) that encountered RBDD with gates in the water during all years of the study. This finding was supported by winter-run redd aerial surveys conducted by the California Department of Fish and Game in 1987 which showed over 96 percent of the winter-run spawning occurred above RBDD. However, recent unpublished CDFG data indicate that this high proportion in upstream winter-run spawning was not realized during 1988, since the dam gates were replaced in the water during February prior to the majority of the winter-run's migration past RBDD.

An additional indication of the effectiveness of raising the dam gates is illustrated by comparing delay for salmon encountering the dam with gates in the water to delay for salmon encountering the dam with gates raised (Table 12, Figure 27). Time spent delayed in the vicinity of the dam with gates raised was greatly reduced compared to the delays that salmon experienced with the gates in the water. Except for 2 winter-run and 1 late-fall run that remained in the vicinity of the dam in excess of 10 hours, most of the other salmon passing RBDD with the gates raised were observed to move to the dam, across the dam foundation, and upstream with no hesitation. All radio-tagged salmon under direct telemetered observation, upon passing the dam during gates-raised operation, passed through the three right side gate bays (gates 9-11), which were in the channel thalweg.

Table 12. Total delay (in hours) at RBDD 1/ for radio-tagged late-fall and winter-run chinook salmon with dam gates in and dam gates out of the water during study years 1986-1988. (Data are means ± SE, range, and numbers of salmon encountering and passing RBDD under each condition).

Run	Gates In	Gates Out
Late-Fall	120.6 ± 36.2	3.0 ± 1.8
	(5.0 - 553.1) n=15	(0.5 - 17.6) n=9
Winter	225.7 ± 76.8	3.0 ± 1.5
	(2.1 - 1429.7) n=23	(0.3 - 15.3) n=11

1/ Within 1,000 feet of the dam.

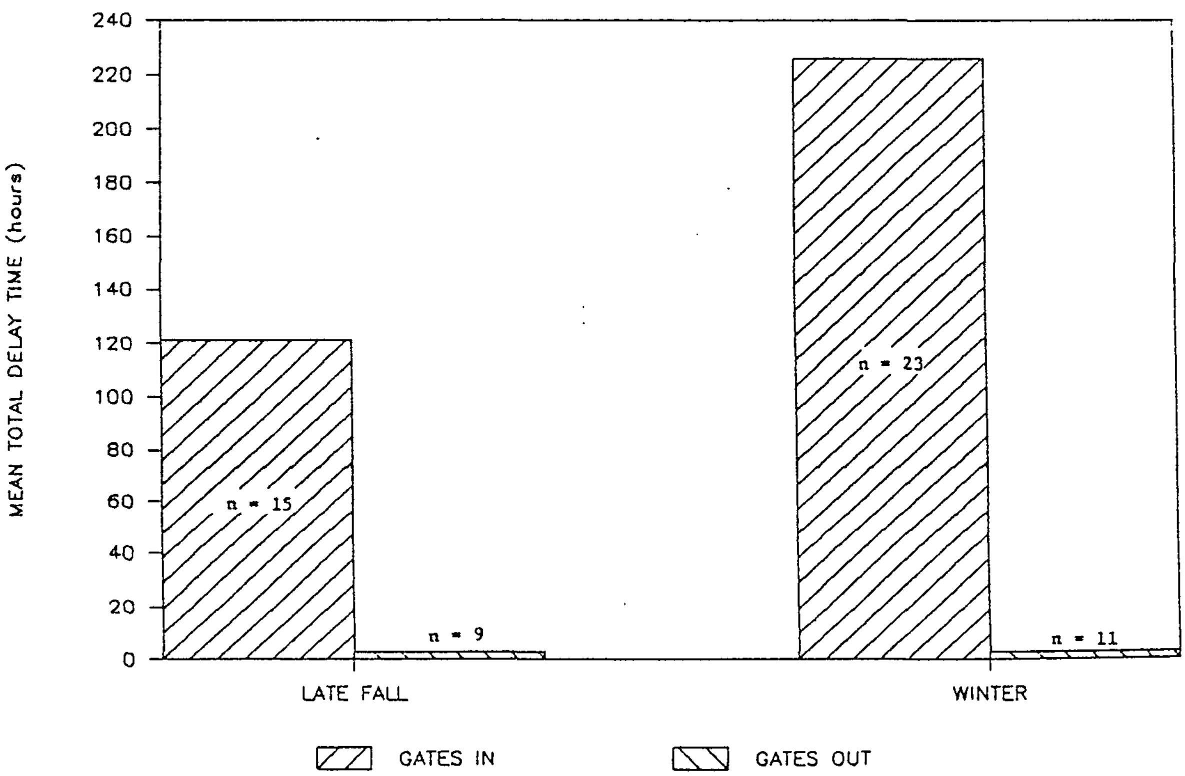

Figure 27. Mean total delays at Red Bluff Diversion Dam for Late Fall-Run and Winter-Run Chinook Salmon with the dam gates in the water and out of the water during the study years 1986 - 1988.

Of all the RBDD operational practices evaluated during 1984 to 1988, raising the dam gates during the non-irrigation season provided the most dramatic improvements in adult salmonid upstream passage as determined by observing the behavior of radio-tagged salmon.

Short-Term Spill Manipulations

We implemented research design modifications, beginning in August 1986, to assess the effects of short-term spill manipulations on the behavior of individual salmon (see Appendix I for methods). This action was based on the previously described difficulty in interpreting results of spill configuration tests and the recognition that, "since the appropriate behavior for an individual fish will depend on the nature of its phenotype (e.g. run, sex, maturity, size) in conjunction with the variability of the environment and activities of others, it can be misleading to frame optimal-behavior arguments in terms of the average individual" (Magurran 1986). The specific behavioral responses of salmon to the various spill manipulations provided immediate measurement of the effect of the manipulation and provided information useful for evaluating methods for improving upstream fish passage conditions at RBDD.

Forty-one separate short-term spill manipulation experiments were conducted between August 1986 and April 1988 using one of five different manipulations:

1) spill increased adjacent to fish ladder,
2) spill reduced adjacent to fish ladder,
3) spill moved entirely away from vicinity of fish ladder,
4) herding spill manipulation, or
5) juggling spill manipulation.

Spill increases or reductions were generally less radical than the other spill

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manipulations and were of a magnitude ranging from 25 to 100 percent of the initial spill adjacent to fish ladders. Each of these spill manipulations is described in detail in Appendix I. Twenty-four radio-tagged salmon were involved in these experiments and ten of these fish were involved in more than one experimental spill manipulation. Complete information for these experiments is given in Appendix II, Table 10 and is summarized in Table 13.

Table 13. Primary response of radio-tagged adult salmon to short-term spill manipulations performed during study years 1986-1988.

	Spill Manipulation				
Salmon Response	Spill Increase Adjacent to Fish Ladder	Spill Reduction Adjacent to Fish Ladder	Spill moved Completely Away From Fish Ladder	Herding Spill	Juggling Spill
Moved into fish ladder	0%	0%	0%	0%	0%
Moved to fish ladder discharge	0%	0%	29%	22%	0%
Moved to/or with spill	30%	30%	57%	44%	40%
Moved downstream away from dam	40%	30%	14%	22%	40%
Moved to calm water behind closed gate(s)	20%	10%	0%	0%	20%
No response	10%	30%	0%	11%	0%
Total number of salmon	10	10	7	9	5

A spill increase adjacent to the fish ladder tended to obscure the fish ladder discharge but provided increased flow in the vicinity of the ladders to attract salmon to the area, which would presumably result in the salmon finding the fish ladder entrances. However, none of the radio-tagged salmon exposed to this manipulation were observed to move to the ladders. Most fish either initially moved downstream upon exposure to the increased spill, but shortly returned to the dam in the vicinity of the increased spill, usually along one of the edges of the discharge, or moved directly to and held in the area of the increased spill. One of the fish that initially moved to calm water behind the closed gates also moved back to the area of increased spill. The single fish that did not apparently respond to this manipulation held in the discharge of a gate opened 2.2 feet and likely did not sense the increased spill near the fish ladder. Most of the salmon attracted to the increased spill moved to gate 1 or gate 11 discharges. These fish were frequently observed within a 50-foot range of a fish ladder entrance and yet were not observed to move to the fish ladders.

Spill reductions adjacent to the fish ladders generally made ladder discharges more apparent and reduced overall flow in the vicinity of the ladders. However, as observed with spill increases, no radio-tagged salmon moved to the fish ladders. The greatest proportion of non-response was observed for this manipulation, likely because it was least radical of all the spill changes. The salmon that did respond moved either into the decreased spill, which led the fish into the gate-bay upstream from the fish ladder entrance (gate openings $\leq$ 1.5 feet), or salmon moved downstream, returning shortly afterward to the dam. One of the salmon in this latter group returned initially to the fish ladder discharge but moved to the adjacent spill and resumed holding.

The movement of spill completely away from the fish ladders and the herding spill manipulation were successful in inducing some salmon to move into the fish ladder discharges. However, the majority of the salmon exposed to these spill manipulations were "spill followers", including those that initially moved downstream only to return to the spill gate discharges. The fish that did move to fish ladder discharges did so only after all spill was moved sufficiently far way to fully expose the fish ladder discharge as the predominant flow in the immediate area. Four of the salmon exposed to these spill manipulations exhibited a secondary or tertiary response by moving to the fish ladder discharges. And two of these fish, in fact, passed the dam within 2 to 7 hours after termination of the herding spill sequence (see Appendix II Table 10).

Juggling spills, the alternate opening and closing of spill gates immediately adjacent to the fish ladders, resulted in salmon moving primarily in unison with the spill changes, or moving away from the dam and shortly returning to the spill discharge. One salmon exposed to this manipulation on two separate occasions exhibited secondary or tertiary responses by moving into a fish ladder discharge, but in each instance resumed holding in the spill discharge.

While consistent and significant improvements in upstream salmonid passage were not realized through the practice of short-term spill manipulations, several useful observations should be noted. The response time of radio-tagged salmon to all spill manipulations was rapid, occurring immediately or within a 10- to 20-minute lag time. When examined collectively, 68 percent of the salmon's primary responses to the spill changes were to follow or hold in the spill discharges or to briefly move downstream and then return to the spill discharges. This behavior reflects a well-developed positive rheotaxic tendency (behavioral orientation into water currents) of adult anadromous salmonids. Most of the salmon observed moving to, or with, and holding in the spill tended to avoid spill discharges with gate openings exceeding 2.5 to 3 feet (excessive velocity and turbulence) and would move or hold along the edge of the air entrainment line or downstream hydraulic "boil". Spill gate openings less than 1.5 feet were observed to allow salmon to move to positions upstream of the fish ladder entrances (i.e., into the gate bay), whereas, spill gate openings of 1.5 to 2 feet were observed to "hold" salmon at a distance about level with the fish ladder entrances (see Figure 28).

In nearly fifty percent of the spill manipulation trials, salmon exhibited secondary and tertiary responses, which may be attributable to the spill manipulations. These actions were combinations of movements through spill discharge areas, areas of calm water behind closed spill gates, and movements into the vicinity of the fish ladders. Over half the salmon (11) exhibiting the additional responses did so by moving near the fish ladder entrances. Except for two of these fish that passed the dam following the "herding spill", the remaining nine salmon eventually moved back to areas behind the spill gates. This was very frustrating to observe, especially since all but one of these nine salmon eventually passed the dam after additional delays, ranging from 10 days to over one month.

On an overall basis, the observations of radio-tagged salmon provide strong indication that, although spill manipulation or set spill

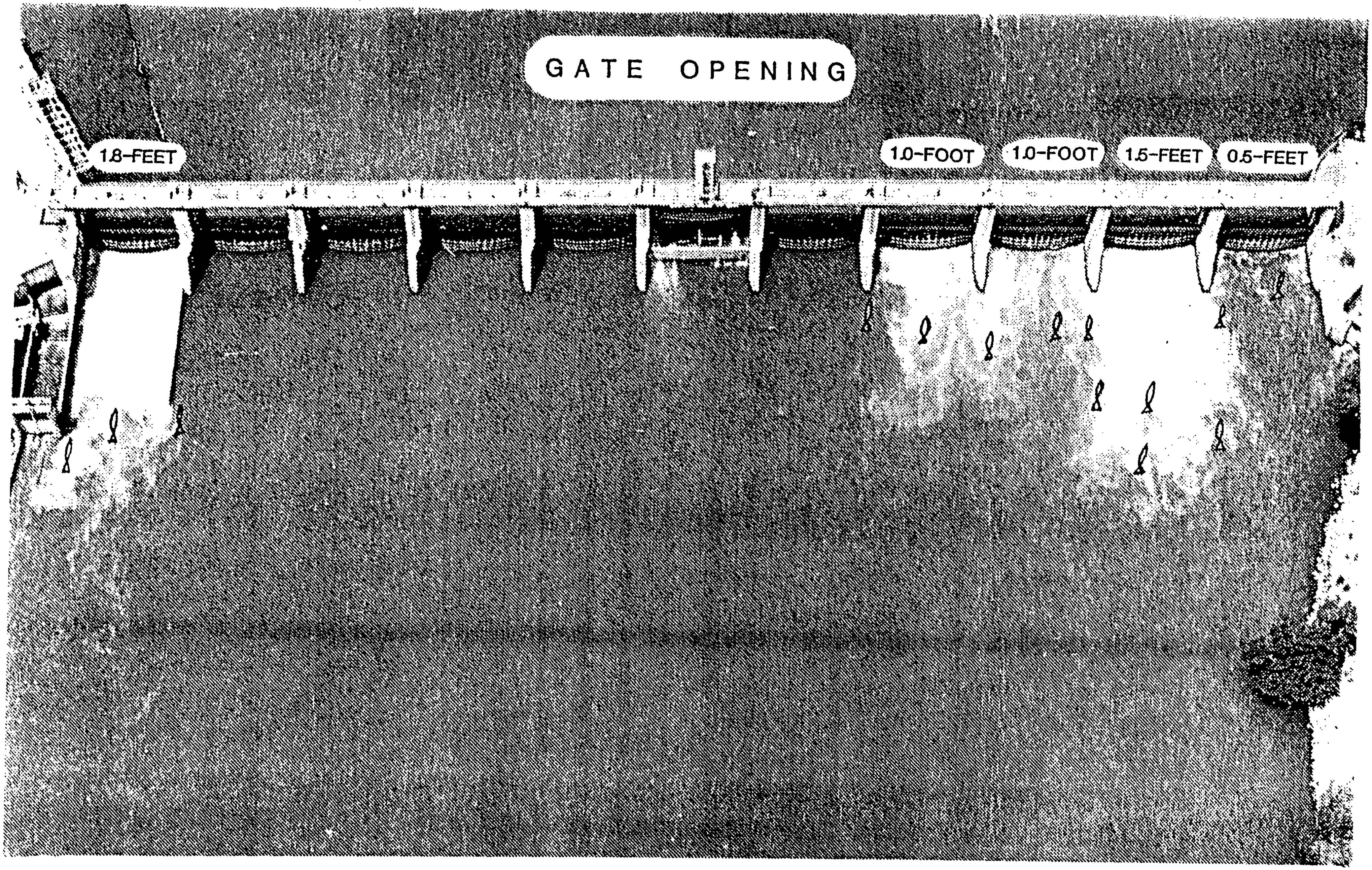

Figure 28. General areas of attraction to spill discharges of 0.5 to 2.0-feet for adult chinook salmon encountering Red Bluff Diversion Dam during upstream spawning migrations.

configurations may be used to attract or guide salmon to the vicinity of the fish ladder entrances, the fish ladder entrances and flows are not adequately attractive for all salmon to enter them under all conditions.

Observations of Specific Salmon Behavior

Additional observations of specific behavior of 26 salmon at RBDD under non-experimental conditions provided useful information in evaluating dam operations affecting upstream salmonid passage.

Observations on the behavior of 22 radio-tagged salmon upon first arrival at RBDD were collected from July 1986 through April 1988. Fifteen of these salmon were under observation immediately or shortly after initial arrival at the dam and seven of the salmon were observed during the first daylight period following night-time approaches to RBDD. Data for these observations are tabled in Appendix II Table 11. Initial encounters with the dam were dominated by salmon moving behind or immediately adjacent to spill gate areas releasing the greatest percentage of spill. Two fish moved directly to the left bank fish ladder discharge upon first encounter with the dam only to move to and hold in spill discharging through gates 1 or 2. Two fish initially approached the dam behind closed spill gates. Most salmon were active and exhibited a considerable amount of movement within and between various discharging spill gates and the fish ladder discharges. Of the seven salmon that showed subsequent movement to the fish ladder discharges shortly after arrival, four entered a ladder and passed the dam; the remaining three salmon were observed to return to areas of spill. These behaviors are consistent with those observed during experimental spill manipulations, in that 1) salmon appear to key their orientation on gate discharges, and 2) salmon moving in the fish ladder discharges frequently do not enter the ladders, but return to the gate discharges.

Radio-telemetered observations of nine spring- and fall-run salmon as they entered and ascended the fish ladders were obtained from 1986 to 1987 and are presented in Appendix II Table 12. These observations revealed that radio-tagged salmon predominately moved into the fish ladder adjacent to the spill gate(s) area releasing the greatest percentage of total discharge. River flows ranged between 4,570 and 10,380 cfs during the course of these observations, and total delay prior to dam passage was generally less for those salmon passing at the lower river flows. Appendix II Table 12 shows a general relationship that the shortest delay times observed occurred when combined discharge from the ladders was 10 percent of the total river flow or greater. These relationships were also observed by Hallock et al. (1982), i.e.,: 1) a positive correlation between delay and river flow, and 2) a negative correlation between delay and percentage of total dam discharge issuing though the fish ladders. In all cases, when salmon moved within the fish ladders, they ascended and exited the ladders rapidly (ranging from 15 to 30 minutes). It is clear from those observations that upstream salmon movement is not impeded within the fish ladders.

The combination of results from the spill experiments and observations of the specific behavior of individual salmon at RBDD illustrate the fact that while spill manipulation may be used to guide salmon within the vicinity of the fish ladder entrances, the response of chinook salmon (whether or not to enter the fish ladder) is highly variable. This behavior likely contributed to the extreme variation of salmon delay times in the spill configuration experiments. Although behavior of radio-tagged salmon blocked by the dam was highly variable during the course of the study, these salmon spent an average of seven days just below the dam before eventually dropping further back downstream (Appendix II Table 9). This general tendency may be an indication of an upper threshold beyond which most salmon cease their attempts to locate the fish ladders.

The most significant indication from all the specific behavior observations and the documented excessive delay and blockage of salmon at the dam (Table 7) is that the existing fish ladder entrances do not provide adequate attraction for most salmon that encounter the dam.

Fish Ladders

Right and Left Bank Fish Ladders

Operation of the RBDD fish ladders for optimal attraction and passage of upstream migrating salmonids is essential to achieving management goals for chinook salmon and steelhead trout in the upper Sacramento River. During our studies, every effort within our authority was made to ensure that fish ladders operated according to the established operating criteria in the Designer's Operating Criteria for RBDD (1970). However, there are two factors that are crucial to proper fish ladder operation which required frequent attention and maintenance.

Fish passage was periodically disrupted because the grates on auxiliary water diffusers in the ladders were chronically clogged with debris and had to be cleared either by shutting the ladders down and pumping diffuser chambers dry, which frequently took 2 to 5 days, or by SCUBA divers using knives or rakes to dislodge the debris. Furthermore, trash rack conveyer units installed to remove debris from the fish ladder diffuser chambers were problem-plagued. Constant corrective maintenance and repair were required on the left bank fish ladder unit and the right bank unit remained inoperative for most of the time period following its installation. Since most of our experimental spill trials and observations of radio-tagged salmon behavior occurred during periods of full-capacity or near full-capacity diffuser performance, and because results indicated suboptimal salmon attraction to the fish ladders under those conditions, we firmly believe that less than full-capacity operation of fish ladder diffusers severely impedes salmon passage at RBDD. The previously presented results probably represent a "best case" situation with the existing ladders.

The gates used to regulate the head differential at the fish ladder entrances were the second factor requiring frequent attention. These gates were originally designed to function automatically to maintain a proper head differential (Designer's Operating Criteria for RBDD, 1970). However, the automatic control system has not functioned since 1975 and the fish ladder head differentials have been maintained by manually adjusting the gates on an intermittent basis. Additionally, no means of actually measuring the head differential was in place and so it had to be visually estimated for adjustment. This practice led to a certain amount of inconsistency in head differential adjustment that varied with the person adjusting the gates or fluctuations in tailwater elevations, which can change drastically during storm events and with changes in water releases at Keswick Dam. This problem was most severe during periods of changing tailwater elevation. For these reasons, in January 1987 when the dam gates were raised and the ladders were out of operation, we applied graduated marks immediately upstream and downstream of the head regulating gates of both ladders so that manual adjustment would be as precise as possible to maintain appropriate head differential during subsequent ladder operation.

We discussed these problems with a USBR electrician during the spring of 1987. As a result, he designed an electronically automated control system for regulating fish ladder head differential which was installed in both ladders and began operation June 1987. Under changing tailwater elevations this particular control arrangement did not appropriately respond to maintain a proper head differential. Subsequently, modifications to the automation system were designed and installed during May 1988 and its performance is presently being monitored; recent observations indicate the device is functioning properly.

As noted for the auxiliary water diffusers, although suboptimal salmon attraction to the fish ladders occurs even when the head regulating gates are properly adjusted, improper adjustment of these gates will most likely contribute to severe impedance of salmon passage at RBDD. While experimental evaluation of head regulating gate adjustment was not conducted, several observations regarding their function are useful to this discussion. Limited observations and measurements of the fish ladder discharge velocities at various head differentials during the course of these studies indicated that turbulence is high for head differentials of nine inches or more. This turbulence may confuse or repel some salmon, because the discharges at RBDD are the first major turbulent water that adult salmon migrating up the Sacramento River encounter. Measurements of ladder discharge velocities indicated that an 18-inch differential generally provides on average 6- to 8-feet-per-second water velocities, which is considered a desirable ladder attraction flow for salmon (Bell 1984). However, as stated above, there is considerable turbulence at this head differential and velocities generally fluctuate widely. The close proximity of the diffuser chambers to the ladder entrances and the chambers' general configuration creates much of the turbulence and erratic velocities. This problem is further exacerbated when the diffuser chamber grates become plugged with debris because of reduced opening to pass the diffuser flow.

The responsibility for operation and maintenance of the RBDD ladders is clearly defined in a 1977 Memorandum of Agreement (MOA) between the Service and the Bureau. According to the MOA, "the Service shall be responsible for the operation, maintenance, and replacement of ... the left and right bank fishways including left bank trash rake and trash rack . . .". Within the Service, those responsibilities are assigned to the Tehama-Colusa Fish Facilities. The agreement further states that "the Bureau shall accomplish operation, maintenance, and replacement of facilities, which are the responsibility of the Service, when labor, equipment, or materials are requested by the Service on a reimbursable basis."

Based on our observations and studies at RBDD, we believe past operation and maintenance of the fish ladders were inadequate to ensure optimal operation of the fish passage facilities. Preventative maintenance for the fish ladders was rare. Most maintenance that was done on the ladders took place after the occurrence of an identified fish passage problem (e.g. clogging of diffuser intakes or diffuser chamber grates, machinery breakdown, or a decline in fish counts). In our opinion, Tehama-Colusa Fish Facility personnel responsible for the operation and maintenance lacked the necessary expertise in identification of fish passage problems and ensuring optimal performance of fish passage facilities. In addition, it appears that adequate funding to ensure proper operation and maintenance of the ladders has historically been deficient. We believe these factors were probably significant contributors to past fish passage problems at the dam.

In addition to the previously stated problems with the operation and maintenance of the fish ladders, we realized that the relative position of the fish ladder entrances may also inhibit passage by salmon. During the course of the behavioral observations of salmon at RBDD, a general tendency of the radio-tagged salmon to seek shaded areas was noted. Shade was in the form of shadows cast from the structure of the dam in the late afternoons. Radio-tagged salmon were frequently observed to move and hold in these shaded areas. These observations and the general tendency for salmon to migrate and hold at depth, especially in rivers of moderate to shallow depths, led us to conclude that the fish ladder entrances may be too near the water surface. Because salmon must move near the surface to enter the existing ladders (within 3-5 feet of the surface), the effect of increased light intensity or some other factor may deter some salmon from attempting such maneuvers, especially during the mid-day period.

Gate 6 Ladder

An experimental removable center-dam fish ladder was installed at gate 6 on the dam for short periods during 1984, 1985, 1986, and 1988. The ladder could not be installed during 1987 because the removable stop logs necessary for the ladder's installation were required for installation of the flip-gate on Gate 11.

1984 Operation. The configuration of the 1984 gate 6 ladder was a series of four pools created by 5 large overflow weirs from Lake Red Bluff to the river below the dam. The upstream and downstream weirs were positioned parallel to the axis of the dam at opposite corners of the gate 6 bay. The three center weirs were positioned perpendicular to the axis of the dam. The three center weirs had submerged orifices which were in line with one another.

During the period from initial operation of the gate 6 fish ladder on September 13, 1984 until the removal operation began on November 27, 1984, significant modifications were periodically made to the fishway structure based on observations of the ladder's performance.

Initial observations of water flowing through the ladder revealed that excessive turbulence was created within the ladder pools and at the ladder's downstream entrance. The turbulence within the pools was attributable to the submerged in-line orifices at the base of the three center baffles. Originally, it was assumed that those anadromous salmonids not leaping over the baffles could swim through the submerged orifices. However, it was quickly recognized that the combination of the substantial head differential between baffles and the in-line arrangement of the orifices created velocities higher than those salmon could negotiate and created undesirable turbulence within the ladder. This was particularly evident in the downstream-most pool where high velocity water exiting the downstream-most submerged orifice slammed against the RBDD abutment immediately adjacent to the entrance to the ladder. It was also obvious that this surging action and the flow over the irregular-shaped surface of the downstream steel stoplog created undesirable turbulence at the ladder entrance. Salmon were observed leaping in a diagonal direction toward the ladder entrance which resulted in fish either hitting the concrete abutment or landing in the strong surge of the water exiting the first orifice and being subsequently washed back out of the ladder. The Bureau alleviated these two problems by sealing off most of the area on each of the three submerged orifices and clamping plate steel horizontally over the irregular-shaped surface of the downstream steel stoplog. These two measures substantially reduced turbulence within the pools and at the ladder entrance.

There were numerous additional problems that plagued the ladder's performance during 1984. These included: extreme turbulence in the ladder resulting from excessive flow, extreme and highly variable head differential between pools, excessive water leakage at undesirable locations, and an inability to properly adjust the ladder.

One hundred-fifty-three fish passing through the gate 6 ladder were visually enumerated by the fish counters during 1984. The use of a person positioned immediately adjacent to the ladder to count fish was not very successful; this technique was only considered an interim measure until such time a better method could be implemented. Numerous problems with the use of this technique were quickly evident during the fall of 1984 and detracted from the accuracy and effectiveness of the gate 6 fish ladder evaluation. Fish counting could not be conducted during considerable periods because numerous attempts at structural modifications required ladder dewatering at various times from September through November 1984.

Salmon observed within the ladder frequently made several attempts before successfully negotiating passage into upstream pools. Given the apparent velocity and turbulence problems, the approximate 2.75-foot head differential between pools appeared to be difficult for most salmon to negotiate.

<u>1985 Operation</u>. The design of the gate 6 fish ladder installed in 1985 was substantially different than the design of the 1984 gate 6 ladder. The 1985 gate 6 ladder had two overflow weirs (at the entrance and exit), five baffles with submerged orifices, and six pools with approximately a 2.0-foot

head differential between pools. This design proved to be a significant improvement over the 1984 design.

Installation of the gate 6 fish ladder in 1985 was completed on August 14 and the ladder went into operation on August 16. The ladder was removed from operation on November 14, 1985. Based on initial observations of the ladder's performance, several significant modifications were made to improve the ladder's effectiveness.

Prior to August 14, several attempts to place the ladder into operation revealed that a significant amount of leakage under the wooden baffles was occurring which created excessive turbulence within the pools of the ladder and made it extremely difficult to properly adjust head differentials between pools. Following these observations, SCUBA divers conducted an underwater inspection of the ladder with the ladder shut down and subsequently sealed all major leaks with rubber seals.

Observations of the ladder's performance after August 16 revealed that the flow exiting the ladder was not sufficient to attract significant numbers of salmon into the ladder. For this reason, attraction water was added to the lowermost pool by creating an overflow from Lake Red Bluff directly into the bottom of the fish ladder. This modification was completed on August 22 and the ladder's first day of operation with attraction water was on August 23, 1985. Significant numbers of salmon were seen using the ladder shortly following the addition of the attraction water.

After some experimentation, a flow of approximately 40 cfs entering the uppermost pool of the ladder and a flow of approximately 25 cfs added to the lowermost pool as attraction water appeared to be satisfactory; higher flows entering and coursing through the ladder created excessive turbulence and a lesser volume of water exiting the ladder did not attract sufficient numbers of salmon.

Periodic inspections of pool elevations in the ladder revealed that the sliding wooden gates controlling the flow through the submerged orifices in each of the baffles had to be periodically adjusted to maintain a constant head differential between pools. As the season progressed. it became increasingly difficult to make those adjustments because of swelling in the wood.

Three of the wood baffles inside the ladder had submerged orifices positioned against the steel stoplogs and along the curved shape of the RBDD concrete weir. This configuration created an obvious backroll effect of surface water in pools receiving water through these orifices. Numerous salmon were periodically observed in those pools actively swimming in an orientation facing downstream.

As the river flow decreased in the fall and the water surface elevation downstream of RBDD lowered, it became increasingly difficult to maintain proper head differentials between pools in the ladder. Because the downstream-most weir elevation was not adjustable, the depth of water over the weir became shallower as river flows decreased which made it more difficult for salmon to enter the ladder. During most of mid-October to mid-November the ladder remained out of adjustment.

Fish using the gate 6 ladder during 1985 were counted with use of a live video camera positioned in a vantage point above the ladder. A monitor for this camera was incorporated into the existing two-monitor setup at RBDD so that one technician could simultaneously view all three monitors. This technique was a significant improvement over the on-location counting technique used in 1984, however, several spot checks of the accuracy in fish enumeration revealed that the technicians were underestimating actual fish passage to some degree. After experimentation of fish counting with use of a video cassette recorder and a second camera, we believe the underestimation was attributable to either fish passing over the flashboard in a position outside the field of view of the main video camera or fish passing over the flashboard in shadowed areas where their detection would be difficult. Fish movement over the flashboard was noted to be very rapid which would also make detection difficult to a person watching three separate monitors.

We estimated that more than one thousand salmon passed through the gate 6 fish ladder during 1985. This approximation is based on the actual fish counts (638 salmon), adjustments for the 10-minute per hour periods when the technicians were on break, nighttime passage, and the three-week period prior to the video equipment installation. Although the video equipment was not installed during the ladder's initial operation which prevented a complete fish count, substantial fish activity through the ladder was observed during the second and third week of the ladder's operation (following the addition of attraction water to the lowermost pool); fish passage during this interval was believed to be large. For example, on August 24, 11 salmon were observed passing through the ladder in a 45-minute period and on August 27, five salmon were counted passing through the ladder in a 15-minute interval. No attempt was made to precisely estimate fish passage during this several-week period but we believe that several hundred salmon is probably a good approximation based on periodic observations.

1986 Operation. The basic design of the gate 6 ladder installed in 1986 was the same as the ladder installed in 1985. However, based on observations made in 1984 and 1985, several refinements were made to the gate 6 ladder in 1986 to improve its performance. The most significant modification was that the submerged orifices of those baffles positioned perpendicular to the RBDD concrete weir were made rectangular in shape and positioned off the bottom of the concrete weir so that the bottom of the orifice was above the highest point on the concrete weir; the outside edge of these orifices was positioned no closer than 1 foot from the steel stoplogs. In addition, the flow through the submerged orifices was easily adjustable by one person with the use of a metal mechanical control gate on each orifice. The addition of a video cassette recorder used in conjunction with a video camera greatly improved the accuracy and ease of counting fish passing through the ladder.

The ladder was placed into operation on August 18, 1986 and removed from operation on November 3, 1986. During that period, an estimated 4,139 chinook salmon and 82 steelhead passed upstream through the ladder. The average fish passage per day (61) and the proportion of all fish passing the dam utilizing the gate 6 ladder (5.3%) increased dramatically as compared to somewhat similar periods (late summer and early fall months) in 1984 and 1985 (Table 14).

Table 14. Fish passage through the gate 6 fish ladder during 1984, 1985, and 1986.

	Total Days of Operation	Total Number of Chinook Salmon	Mean Fish Passage/Day	Proportion of Total Number of Salmon Passing the Dam
9/13/84 - 11/27/84	76	153 1/	2 1/	0.5 %
8/16/85 - 11/14/85	91	1,000 1/	11 1/	1.3 %
8/28/86 - 11/ 3/86	68	4,139 2/	61	5.3 %

1/ Minimum estimate.
2/ Does not include an estimated 82 steelhead trout.

1988 Operation. The design of the gate 6 ladder installed in 1988 was the same as in 1986. It was placed into operation on June 18, 1988 (the earliest date of installation) and was still in operation at the submission date of this report, so no detailed evaluation of the 1988 operation will be included here. However, based on fish counts and the proportion of fish using the gate 6 ladder versus the side ladders through August 31, 1988, the gate 6 ladder performed very well. During this period, 5,968 salmon were counted through the ladder which represented more than 15 percent of all fish passing the dam. Thus, the gate 6 passage represents a considerable increase in the proportion seen in earlier years (Table 14 and Figure 29).

The main drawback of the gate 6 ladder is the inability to utilize the ladder during high river flow periods when salmon passage conditions at RBDD are particularly poor. The ladder has to be removed during the flood season to prevent adverse hydraulic conditions at the dam. However, operation and experimentation with the ladder since 1984 have shown that improvements in salmon passage can be derived from an additional fishway at the dam during the non-flood season.

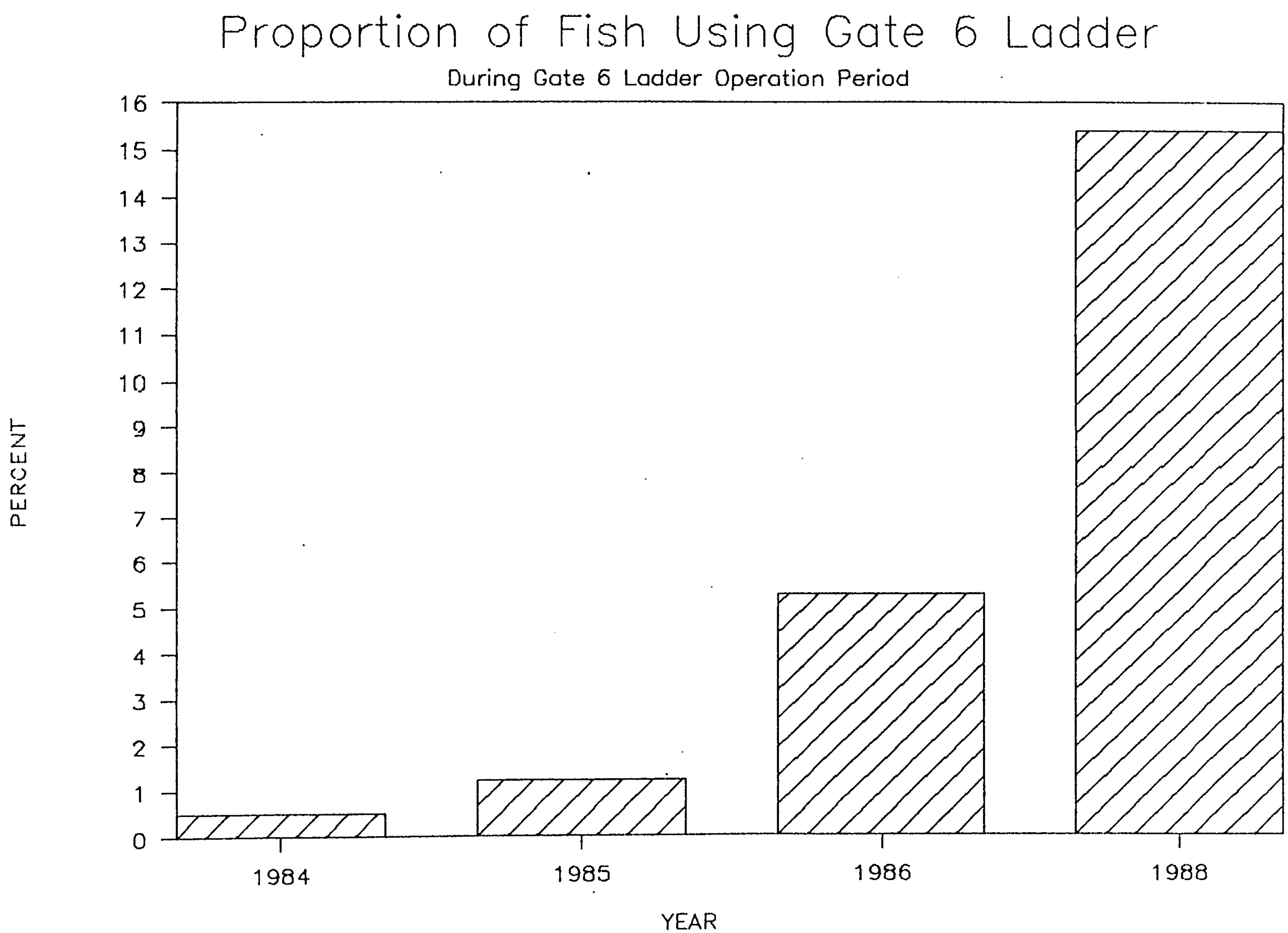

Figure 29. Proportion of all adult salmon passing Red Bluff Diversion Dam which utilized the gate 6 fish ladder during the gate 6 ladder operation period.

CONCLUSIONS AND RECOMMENDATIONS

Downstream Migrant Salmonid Passage

Conclusions

1. Passage of downstream migrant chinook salmon at RBDD occurs every month of the year. Fry-sized salmon (30-40 mm) and smolt-sized salmon (>80 mm) migrate past RBDD every month of the year. During wet years, the greatest numbers of emigrants occur in the winter months as fry-sized fish and in dry years the greatest numbers occur during the spring as smolt-sized fish.

2. Yearly entrainment of downstream migrants through the Tehama-Colusa Canal headworks varied from 0.2 million to 0.6 million. Maximum losses of all downstream migrants at RBDD due to entrainment was estimated at 0.6 percent.

3. Losses of downstream migrants due to physical injury in passage under the RBDD gates is negligible (i.e., at or near 0.0 percent).

4. Physical injury losses of those downstream migrants passing through the Tehama-Colusa Canal headworks fish bypass system was in the range of 1.6 to 4.1 percent. For the duration of the study, these losses represent an estimated 0.10 percent to 0.24 percent of all downstream migrants passing the dam which is significant because of the tens of millions of downstream migrants passing the dam every year.

5. Delays in juvenile salmon outmigration due to the effects of RBDD are negligible, however, delays of juvenile steelhead can be significant during low-flow periods (i.e., 4,000-10,000 cfs). Steelhead

exhibited hesitant behavior in passing under the RBDD gates. More than 20 percent of the steelhead remained in Lake Red Bluff for one week or longer.

6. Predation is the primary cause of downstream migrant salmon mortality at RBDD. Losses due to predation are substantial and may range from 16 to 55 percent. Squawfish are the primary predator at RBDD. Disorientation of downstream migrants due to passage under the dam gates and through the Tehama-Colusa Canal headworks fish bypass system causes increased vulnerability to predators.

Recommendations

1. The new state-of-the-art fish screen and fish bypass system being installed at the Tehama-Colusa Canal headworks to replace the existing fish louvers and bypass system should be evaluated as to its effectiveness in reducing entrainment, physical injury, and disorientation of downstream migrants.
2. Air entrainment in the existing fish bypass system should be eliminated. The new fish bypass system should be designed so that no air entrainment occurs.
3. The gate 11 flip gate should be tested and operated to facilitate the downstream passage of juvenile steelhead.
4. The gates on RBDD should be raised during the non-irrigation season to reduce delay and predation of downstream migrants. The resultant effects on the Tehama-Colusa Fish Facilities and National Wildlife Refuges should be evaluated.
5. A more intensive evaluation of piscine predation in Lake Red Bluff and at RBDD should be conducted.

6. Measures to control predation by squawfish should be developed, evaluated, and implemented at RBDD. These measures could include: a commercial squawfish fishery, trapping and removal of squawfish in the fish ladders, reduction of squawfish holding habitat below the dam, and physical or chemical mechanisms to disperse squawfish concentrations below RBDD and reduce predation. New fishways (described in the following section) will likely improve squawfish passage at the dam and be one mechanism to reduce squawfish concentrations below the dam.
7. The measure of turning off the RBDD high-intensity lights at night to reduce predation should be continued.
8. An evaluation of bird predation at RBDD and Lake Red Bluff should be conducted.
9. Conduct follow-up evaluations of all downstream migrant salmonid passage improvements.

Adult Salmonid Passage

Conclusions

1. Delay and blockage of adult chinook salmon at RBDD are severe. Delay in salmon passage was as long as 1200 hours (50 days) and blockage was as high as 44 percent.
2. Dam spill configurations and spill manipulations within RBDD Standard Operating Procedures were ineffective in improving fish passage conditions. Although only river flows less than 14,000 cfs were tested, there were strong indications that these dam operation measures would not be effective at higher river flows.

3. Raising the RBDD gates during the non-irrigation season dramatically improved fish passage conditions. No blockage of salmon occurred and delays were negligible during these periods. Of all dam operation measures evaluated during this program, raising the dam gates was the most effective in improving upstream fish passage.

4. There are severe problems in operating the fish ladders at maximum design capacity. Problems include chronic clogging of auxiliary water diffuser screens, frequent breakdown and malfunction of diffuser chamber and intake trash rack cleaners, inoperation of ladder entrance differential gate control systems, and lack of routine maintenance.

5. The existing RBDD fish ladders operated at maximum design flow capacity do not provide adequate attraction for adult salmon. Extensive observations of specific salmon behavior below RBDD revealed that salmon frequently move near the vicinity of the fish ladder entrances and do not enter the ladder. Salmon appear to orient movements more frequently toward dam gate spill discharges than to fish ladder discharges.

6. After considerable experimentation and modification, the removable gate 6 fish ladder was useful in passing fish by RBDD during the non-flood season. Ladder installation and removal is difficult and the ladder cannot be operated during the flood season when fish passage conditions at the dam are poorest.

Recommendations

1. Construct a new large-scale state-of-the-art fish ladder on the left (northeast) bank. The exit flow on this ladder should be at least

10 percent of any seven-day sustained flow past the dam (up to 50,000 cfs). The feasibility of specific higher design flows should be evaluated. This recommendation should be evaluated after installation then a decision should be made regarding the feasibility of a new high-flow river bypass on the left bank to improve fish passage.

2. Enlarge the size and flow capacity of the existing fish ladders. The flow and fish entrance depth in each ladder should be at least doubled. The feasibility of specific higher design flows in each ladder should be evaluated. The ladders should be modified to state-of-the-art standards.
3. A permanent program to provide continuous (i.e., daily) monitoring and maintenance of all fish passage facilities should be established. This program would entail on-site routine inspection by a single entity with the expertise, authority, and funding to ensure proper operation and maintenance of fishways at the dam.
4. Use of the seasonal gate 6 fish ladder should continue as an interim measure until new permanent fishways are provided. The ladder should be installed each year as soon as practicable after flood season.
5. Continue the measure of raising the RBDD gates during the non-irrigation season. The resultant effects on the Tehama-Colusa Fish Facilities and National Wildlife Refuges should be evaluated.
6. Conduct follow-up evaluations of all adult salmonid passage improvements.

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